Appendix C

Sediment Source Investigation and Sediment Reduction Plan
for the North Fork Elk River Watershed,
Pacific Watershed Associates, June 1998

PACIFIC
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Sediment Source Investigation and Sediment Reduction Plan for the North Fork Elk River Watershed Humboldt County, California

prepared for

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by

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June, 1998

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Sediment Source Investigation and Sediment Reduction Plan for the North Fork Elk River Watershed, Humboldt County, California

Introduction

The North Fork Elk River watershed is a 22.4 mi^2 tributary to Elk River located approximately seven miles southeast of Eureka, California in Humboldt County (Figure 1). Elk River drains into Humboldt Bay at the southern end of Eureka. The North Fork Elk River is managed for its timber resources largely by the Pacific Lumber Company (P-L), who owns approximately 92% of the watershed. A number of events, including the occurrence of several significant storm and flood events between 1995 and 1997; local flooding in the lower Elk River valley; and increased rates of timber harvesting and road building in the North Fork, have coincided to generate concern about watershed and stream conditions.

At the request of the Pacific Lumber Company, Pacific Watershed Associates (PWA) prepared an analysis of sediment production and delivery to stream channels in the North Fork Elk River watershed. The purpose of the inventory and analysis was: 1) to identify sources of erosion and sediment delivery to stream channels; 2) to distinguish, where possible, between natural, sediment sources and management-related sediment sources; and 3) to determine which future sediment sources are amenable to prevention or control. An additional goal of the assessment was to identify remedial measures and practices which could then be employed to reduce future sediment production and delivery to streams in the watershed.

This analysis and report describes the effects of storms and erosional events which have occured in the watershed over about the last 50 to 60 year period. Old aerial photos from 1954 document the earliest conditions in the watershed for which there are complete records. However, much of the watershed had already been logged by 1954. Stereo aerial photography from a number of later years and decades was used to identify watershed changes that have occurred in the North Fork Elk River over five or six decades of storms and land management. Analysis of historic photos is useful for identifying the nature, location, magnitude and potential significance of the changes which have occurred in the watershed.

Field inventories were conducted in the North Fork Elk River watershed to provide ground-truthing of measured landslide areas, stream channel changes, and channel scour in low order streams (caused by past tractor yarding) which were documented in the aerial photographs. Field surveys were also conducted to determine past sediment production and yield from the road network (including both landsliding and fluvial erosion), as well as the location and volume of future preventable road-related sediment sources. A database of these inventoried sites contains information on past and future erosion as well as recommended erosion control and erosion prevention treatments.

Finally, a brief monitoring plan to track future biological and physical changes in the lower reaches of the main stem North Fork has been proposed. This plan consists of existing monitoring strategies and general protocols as well as additional channel monitoring activities to identify the rate and nature of future changes in channel morphology, aquatic habitat and biological productivity. These permanent monitoring stations can be re-occupied, and variables remeasured, at periodic intervals in the future, to document trends and patterns of channel change.

Geologic setting of the North Fork Elk River watershed

Coastal California north of Cape Mendocino lies on the tectonically active convergent margin of the North American plate. Since the Mesozoic the geologic development of Northern California has been dominated by plate convergence. During the last 140 million years, subduction and the resulting continental accretion have welded a broad complex of highly deformed oceanic rocks to the western margin of the North American plate. These accreted rocks now comprise the Franciscan Complex, which constitutes the basement of the north coast region (Carver, 1992). Throughout the latest geologic period, major uplift of the Coast Ranges and erosional stripping of the regionally extensive forearc sediments are postulated to have resulted from the combined effects of the eastward subduction of the Gorda plate and the northward migration of the Mendocino triple junction (Nilsen and Clarke, 1987). Today Neogene cover sediments are preserved in a series of structural settings such as those found within structurally complex region north of the Mendocino triple junction (Underwood *et al.*, 1984; Nilsen and Clarke, 1987; Carver, 1987).

The bulk of the sediments present within the North Fork Elk River watershed consist primarily of undifferentiated late Miocene through Pleistocene marine sediments of the Wildcat Group which were deposited within an unconfined, late Cenozoic forearc shelf underlain by previously accreted late Mesozoic and early Cenozoic Franciscan Central and Coastal belt and Yager Complex rocks (Stone *et al.*, 1993; Aalto *et al.*, 1995). Wildcat deposits occupy about 69% of the North Fork Elk River watershed area.

The Wildcat Group unconformably overlies the middle Miocene Bear River beds in the subsurface of the Eel River basin and Paleogene and older basement rocks elsewhere in the region (Ogle, 1953; Hopps and Horan, 1983; Ingle, 1976; Clarke, 1992). The Wildcat Group is an apparently conformable sequence of marine mudstones, siltstones and sandstones and an upper sequence of chiefly non-marine sandstones and conglomerates (Clarke, 1992). The Wildcat Group records an eastward transgression during the late Miocene, progressive shoaling from bathyal or abyssal depths, and then infilling of the basin from early Pliocene to early Pleistocene, and then a westward progression of the shoreline during early to middle Pleistocene (Nilson and Clarke, 1987).

Within the study area, the Wildcat Group is mapped primarily as undifferentiated (Ogle, 1953). It outcrops most extensively in the middle and lower North Fork Elk River Watershed)(Map 3) and generally lacks distinctive lithology. The eastern part of the watershed has only a thin veneer of Wildcat sediments which have a gentle regional dip to the west. The section thickens to the west and south. The Wildcat Group in this area is composed primarily of slightly indurated mudstone, siltstone, claystone and sandstone and minor conglomerate. Massive mudstones and siltstones are the most dominant geologic materials. A basal conglomerate and pebbly sandstone is present in parts of Elk River and Freshwater Creek. The Wildcat sediments have been deformed and folded into northwest-southeast trending anticlines and synclines (Map 3). The ridge separating the South Fork

Elk River from the North Fork is a structural arch called the Humboldt anticline which plunges to the west. The main channel of the North Fork Elk River follows the approximate trace of the adjacent down-warp syncline and the ridge between Elk River and Freshwater is mapped as another anticlinal ridge (Ogle, 1953; see Map 3).

To the north of Elk River, within the Freshwater Creek drainage, Knudsen (1993) divides the Wildcat Group into upper and lower units. Knudsen states that the lower Wildcat unit consist of open marine deposits of mudstone, siltstone and fine sandstone. The upper unit is described as being composed of nearshore, bay and fluvial facies and is interpreted as being correlative to the Falor Formation described to the northeast by Manning and Ogle (1950) and Carver (1987). CDMG (1985) describes the Wildcat Formation as "moderately to poorly indurated, massive to poorly bedded, folded, compact, blue-gray clayey siltstones with smaller amounts of sandstone..."

Older rocks of the Yager Complex unconformably underlie the Wildcat Group in the upper North Fork watershed (Map 3). They comprise approximately 9% of the watershed area. The Wildcat Group is thin in the upper North Fork Elk River watershed, and streams have cut through it to expose the Yager Formation in the valley bottoms. The Yager Formation is in fault contact with older, more highly indurated and fractured rocks of the Central Belt Franciscan Formation in the extreme upper (eastern) portion of the basin. The large block of Franciscan rocks in the upper, eastern portion of the North Fork basin comprise about 15% of the total watershed area.

The Yager Complex consists of dark gray indurated mudstones, shales, graywackes, siltstones and conglomerates, with interbedded limey siltstones. These sediments weather to soft clayey materials and are poorly exposed, in contrast to the harder sandstones which are found along streams as boulders. In the Yager Creek and Elk River areas, it appears that the mudstones, siltstones and shales comprise perhaps 70 percent of the total area, while sandstone makes up 25 percent, and the conglomerate less than 5 percent (Ogle, 1953).

In the lower North Fork watershed, undifferentiated, Holocene terrace deposits are found along the main stem North Fork Elk River (Ogle, 1953). These are typically capped with thin, two to ten foot thick deposits of unconsolidated, poorly sorted sands and sandy pebble conglomerate (CDMG, 1985). These deposits are found at elevations of 40 to 120 feet above the present stream channel and are subject to debris sliding and small scale translational slides and slumps on steep slopes or when undercut by bank erosion. Holocene terrace deposits comprise less than 6% of the North Fork watershed.

Slope stability

The Coast Range watersheds of Northern California display some of the most unstable terrain in the Pacific Northwest. Factors influencing slope stability in the North Fork Elk River watershed have not been quantified, but include:

1) **Geologic structure:** dip of beds (dipping down slope nearly parallel to or less than the slope inclination); fractures: weak beds inter-bedded with competent beds; faults; shear zones; and surfaces of weakness are all contributing factors present on the northcoast and each lends to decreased slope

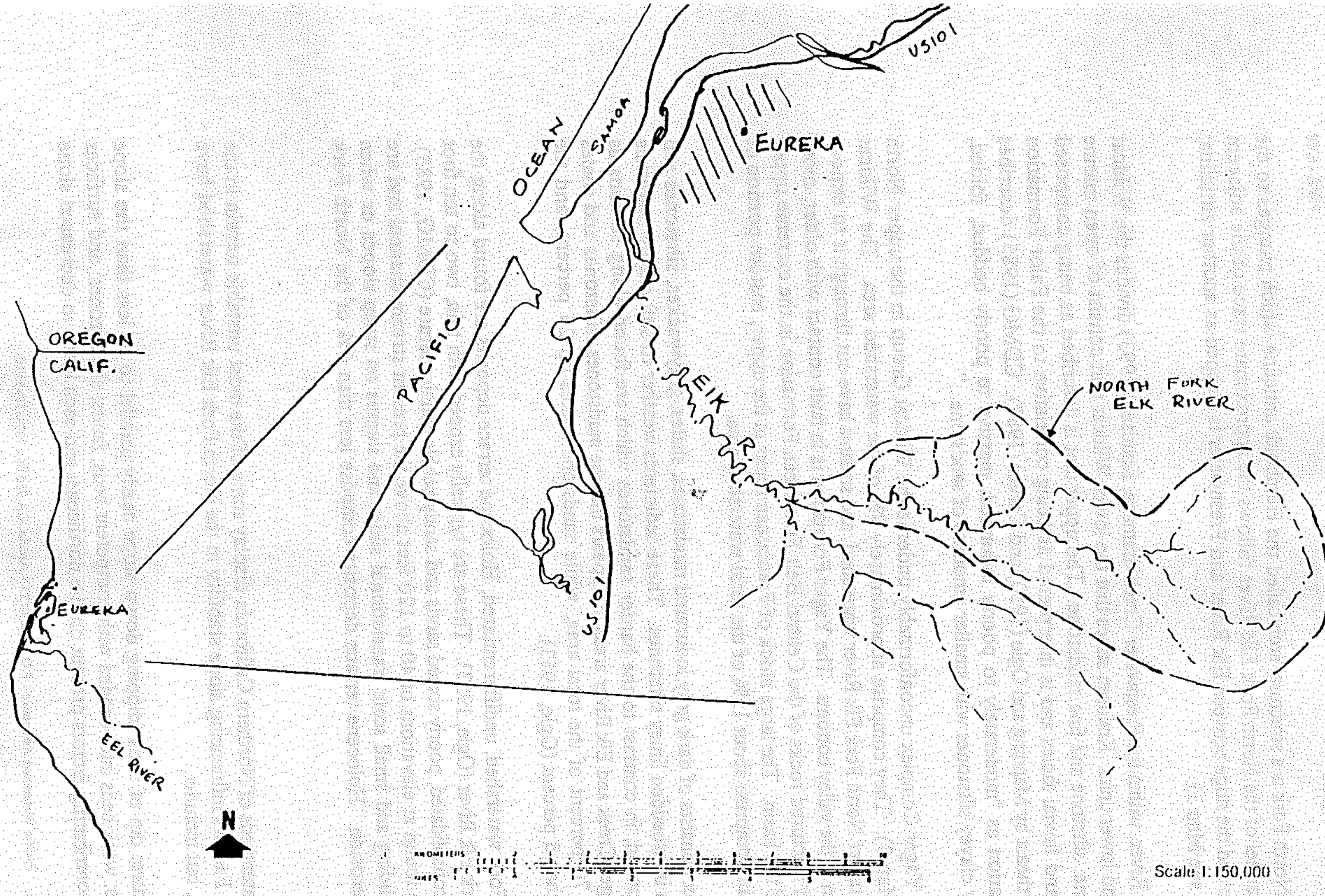


Figure 1. Location Map of the North Fork Elk River watershed.

stability. Geologic structure and bedding orientation appear to influence the location of slope failures in the Wildcat Group of rocks.

2) Material strength: decomposition of materials over time reduces strength; chemical weathering; diminished rooting strength of vegetation following vegetation removal (by fire or harvesting) is important in shallow soils overlying bedrock; widespread, deep colluvium deposits located on steep slopes are factors lending to inherently unstable conditions. Likewise, road and landing construction can change the distribution of mass in steep swales and on potentially unstable hillslopes.

3) Seepage forces reduce resisting forces and increase driving forces. Rainfall and rising water tables, influenced by type and density of vegetation, drainage characteristics of the soils and geology, slope gradient, and rainfall events (intensity and duration) all influence the amount of infiltration and, in turn, groundwater levels and seepage forces.

4) Weather: intense rainfall events are common on the northcoast, and intense and prolonged precipitation events are known to be associated with increased rates of landsliding, especially when high antecedent ground water conditions exist.

5) Slope gradient:

A) Geologic materials have characteristic slope inclinations at which they are stable and just barely stable: residual soils - 30 to 40 degrees; colluvium - 20 to 30 degrees (Hunt, 1994). Slope gradients exceeding these limits are locally common in the North Fork Elk River.

B) Slope inclination is increased by road cuts and sidecasting, as well as by processes associated with stream bank erosion, and the redistribution of material during landsliding events.

C) Tectonic uplift rates can cause both subtle and rapid increases in slope inclination over time. Streams incise in response to lowering base levels, producing steep slopes and steep inner gorges along drainages.

6) Seismic activity, especially the proximity to major earthquake sources, can be an extremely important factor affecting slope stability and the occurrence of landslides. Earthquakes also have a profound effect on the movement of subsurface water through deep colluvial soils, such as those found in Elk River, by cutting off macro-pores and increasing pore water pressures in potentially unstable, steep hillslope areas. The effects of large earthquakes, such as those of 1991-1992, are most likely to express themselves during the first high magnitude storm following severe seismic shaking (ie., the winter of 1996/97).

Steep slopes are the most common locations for landslides in the North Fork. Approximately 12% of the North Fork watershed is comprised of slopes exceeding 65% slope gradient (Figure 2). Slopes over 50%, and especially those over 65%, are most common along the inner gorge of Browns Gulch, on steep slopes south of Scout Camp, in numerous steep swales of Bridge Creek and West Fork

Bridge Creek, in steep swales north of the North Branch, and on inner gorge slopes of the south Branch, the north Branch and the upper main stem (Figure 2). Approximately 60% of the watershed is comprised of slopes which are less than 50% slope gradient.

CDMG (1985) has produced a series of geologic maps for selected watersheds on the north coast of California, including the lower and middle North Fork Elk River watershed. The maps, produced largely through aerial photo interpretation of landforms, depict physical features that "can be correlated to landslide potential, soil erosion potential and stream bank erosion potential." The mapping included the identification of four types of active and dormant landslides (debris slides, translational/rotational slides, earthflows, and debris flows/torrent tracks). Several features indicative of past landslide activity, including debris slide amphitheaters, debris slide slopes and inner gorges were also identified. Finally, one mass movement feature that has been depicted as a complex landslide, produced irregular, hummocky ground in the South Branch North Fork (CDMG, 1985).

The most dominant geologic group in the North Fork Elk River watershed, the Wildcat Group, is locally known for instability and relatively high erosion rates. Its silty and sandy composition, together with its low to moderate induration, results in weathering and the development of granular, non-cohesive soil materials. Weathering on steep slopes produces surface horizons of silty and sandy soil material underlain by unweathered, comparatively resistant, indurated siltstones and fine grained sandstones. These underlying indurated (hard) materials can be barriers to vertical groundwater movement and represent potential slip surfaces for landsliding. Most recent debris slide scars in the watershed expose these underlying relatively hard, impermeable indurated bedrock surfaces.

Some of the steep streamside topography of the most dissected terrain of the North Fork is thought to have been sculpted by numerous debris slide events (CDMG, 1985). Steep swales and inner gorge slopes, combined with shallow soils and colluvium, and weak bedding planes running parallel or nearly parallel to the hillslope, are factors which contribute to local debris sliding in the Wildcat Group (CDMG, 1985). The most apparent debris slide slopes are depicted on the CDMG watershed maps (Map 3). They include selected inner gorge slopes and unnamed tributary swales along the main stem, as well as the steepest slopes and swales in major tributary sub-basins such as Dunlap Gulch, Browns Gulch, Bridge Creek, McWhinney Creek, the South Branch North Fork, North Branch North Fork Elk River and the upper North Fork Elk River.

According to earlier mapping, slopes underlain by bedrock of the Yager Formation and the Central Belt Franciscan Formation in the upper watershed have a higher concentration of large landslides, earthflows and small debris slides than do slopes composed of Wildcat rocks (CDMG, 1985). This, in part, may be a function of the preferential exposure of the Yager Formation rocks in the lower, steeper hillslope locations and the occurrence of the Freshwater Fault zone, and associated deformed and weathered bedrock materials, which juxtaposes the two older rock types (see Map 3).

Methods

The sediment source assessment for Elk River was comprised of three elements: 1) an aerial photo analysis of mass wasting, 2) field sampling of debris slides, bank erosion, and small channel scour, and 3) a complete field inventory of all road related sediment sources.

Aerial photo analysis

To understand the relationship between landslide occurrence, storm/flood events, geomorphic/geologic conditions and land use, we analyzed landslide occurrence in the Elk River watershed from six different sets of vertical aerial photography: 1954, 1966, 1974, 1987, 1994 and 1997. Each new landslide or erosional feature which appeared on the photographs was assigned a unique site number and characterized using a variety of factors. These factors included:

1. Year of appearance (photo year)
2. Feature type (debris landslides, debris torrent source areas, deep seated landslides, debris torrent tracks, bank erosion, enlarged channels, stream crossings and gullies),
3. Certainty of interpretation (definite, probable, questionable),
4. Feature dimensions (length, width),
5. Aspect (compass direction),
6. Sediment delivery (estimated <25%, 25-50%, 50-75%, 75-100%),
7. Type of stream receiving deposits (perennial, intermittent, ephemeral),
8. Land use history at initiation point (road, skid trail, tractor clearcut (<15 and >15 years old), cable clearcut (<15 and >15 years old), partial cut, advanced second growth, unmanaged),
9. Geomorphic association (inner gorge, swale, break-in-slope, headwall, etc.), and
10. Hillslope steepness passing through initiation point (from topographic map)

Debris torrent source areas were classified as debris landslides which turned into debris flows and scoured some length of natural stream channel downstream from the origination point. Debris torrents typically scoured the bed and banks of the channel in the higher gradient reaches (called torrent tracks) and then deposited their load of sediment at stream junctions or in lower gradient reaches (enlarged channels). During the analysis phase of the project, landslide lengths, torrent channel lengths, bank erosion lengths and enlarged channel lengths measured from the aerial photography were corrected using a multiplier based on slope gradients measured from topographic maps. Landslide depths were applied based on field sampling of landslides in North Fork Elk River and existing data from nearby watersheds.

Field sampling

Approximately 3.6 miles of the lower 8.6 miles of the main stem North Fork Elk River was inventoried in three sample reaches for bank erosion and stream bank landslides. These channel reaches were surveyed in the field to identify and quantify dimensions (length, width and depth) of stream side landslides and bank erosion. A number of landslides identified during the aerial photo analysis were also visited in the field to determine and field-verify hillslope gradients, landslide dimensions and actual sediment delivery. Landslides and landslide deposits were measured using tape, string chain and range finder. Results from the field sampling program were used to assign landslide depths, torrent scour volumes, and bank erosion rates for features and sites identified on aerial photos but not visited in the field.

Road Erosion Inventories

A road construction history map was prepared for the North Fork Elk River watershed using the same six sets of aerial photographs used in the landslide inventory. All roads were then field inventoried for past erosion and sediment delivery, including road and landing fill slope failures, stream crossing washouts, stream diversion gullies and sites of road surface and ditch erosion. Field crews traced each erosion feature downslope to determine dimensions (length, width, depth, volume) and past sediment delivery. The cause and age (decade) of each road-related sediment source was recorded, as were a number of geomorphic and land use associations (see data form, Appendix A).

Channel scour of sediment which had been mechanically deposited in low order stream channels during earlier logging activities (1880s and 1920s-1970s) was measured at a number of sites. Most of the channel filling of first and second order stream channels appears to have originated during early tractor yarding from the 1940s through the 1970s. Forest practice rules in the 1980s effectively ended yarding down stream channels and stipulated that all temporary stream crossing fills would be removed upon the completion of operations. Aerial photography from 1954, 1966 and 1974 was analyzed to determine the frequency with which low order channels were impacted by tractor yarding along all or a portion of their length. Field measurements were then used to assign average scour dimensions for these "filled" channels. These measurements were then applied to small order stream channels within tractor yarded areas from these three time periods (pre-1954, 1955-66 and 1967-1974) to produce an estimate of past sediment yield.

The inventory of sediment sources along roads also included a variety of site information about future (expected) erosion and sediment delivery from the road system itself. Information included the identification of unstable and potentially unstable fill slopes, potential erosion at stream crossings (from a variety of sources, including both stream crossing wash out and stream diversion), active gullying, and road surface erosion. Future erosion sources were identified and quantified only if they had the potential to deliver sediment to a stream channel. Thus, cut bank landslides (and other potential and existing erosion sources) were not included in the survey if they would not result in sediment delivery.

For each future sediment source, a variety of site information was collected. Stream crossings were evaluated for the type and adequacy of drainage structures (most stream crossings were either Humboldt log crossings or culverts), the potential for stream diversion, the potential for culvert plugging, and outlet erosion. Field measurements (profile and cross-sections) were entered into a computer program to determine the volume of fill in the crossing, and to estimate the amount of fill that would have to be excavated to either decommission the road or to upgrade the culvert where it is undersized. Each stream crossing was also evaluated for the potential contribution of road runoff and fine sediment from the road surface and ditch to the stream. The length of road and ditch draining directly into each stream (typically through the ditch to the culvert inlet) from the adjacent road was measured for all stream crossings and other road drainage locations (ditch relief culverts) which were delivering sediment to stream channels.

For potentially unstable fill slopes (sidecast), the volume of unstable fill was measured, as was the distance to the nearest stream channel and the gradient of the hillslope below the instability. This, and other data, provided information useful for determining the likelihood and potential magnitude of the unstable material that, if it were to fail, would be delivered to the stream.

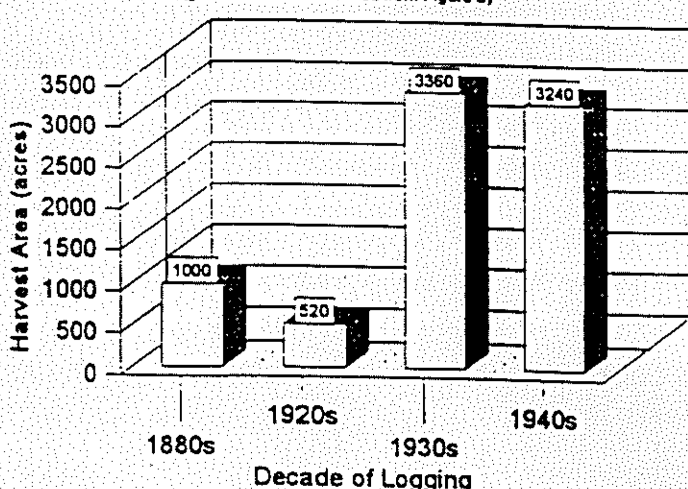
The data on future sediment sources also included information on the likelihood of the potential erosion, erosion and delivery volumes, recommended erosion-prevention treatments, equipment and labor requirements, estimated treatment costs, and treatment priorities for each identified site. These and other data have been assembled in a computer data base and described in an implementation plan (presented in a later section of this report) for road-related erosion prevention and erosion control.

Results and Discussion

Land use history

Logging in the North Fork Elk River watershed began in the 1880s, with steam donkey and/or oxen yarding in the lower watershed up to about the confluence with Bridge Creek (Figure 3). Steam donkey and railroad logging originating in the adjacent Freshwater Creek watershed to the north spilled over into the northern ridge tops and slopes of the North Fork Elk River in the 1920s. Railroad logging expanded into upper Doe Creek, McWhinney Creek, Bridge Creek and Browns Gulch in the 1930s (Figure 3). In the 1930s and early 1940s railroad logging and early tractor logging spread south along the main stem North Fork as well as the entire North Branch North Fork Elk River. In the pre-1950 period, just over 8,100 acres of P-L lands in the North Fork Elk River had been logged (Figure 4).

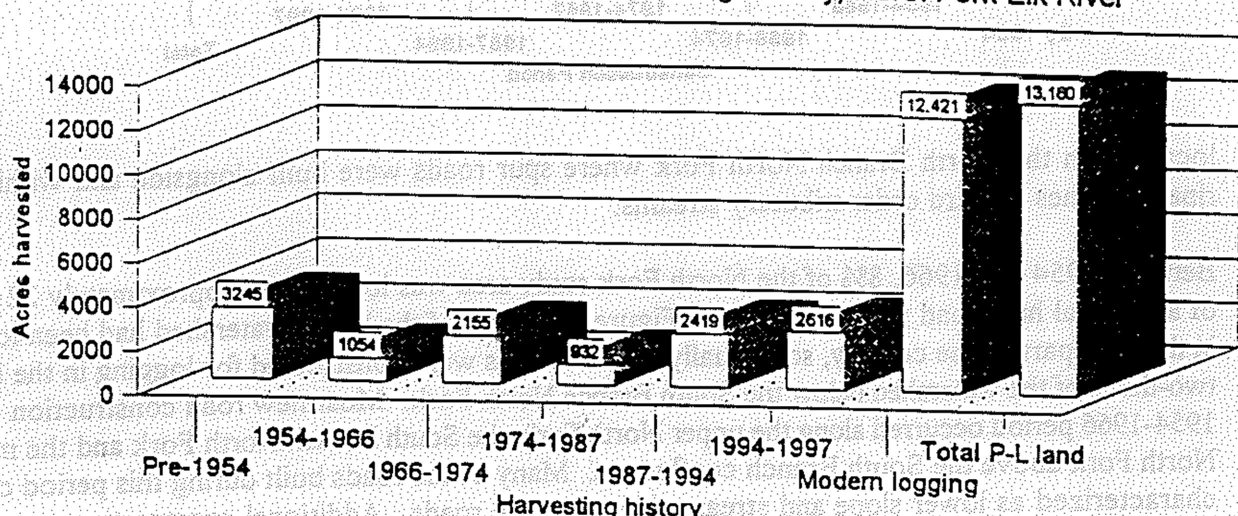
Figure 4. Pre-1950 Logging, North Fork Elk River
(generalized data derived from Figure 3)



A transition in logging technology, from steam donkey cable yarding and railroad hauling, to tractor yarding and truck hauling took place in the North Fork in the 1940s. Analysis of aerial photos reveals that in the pre-1954 period, approximately 2,850 acres of the North Fork had already been tractor logged. Cable yarding (the last of the steam donkey era) had diminished to less than 500 acres.

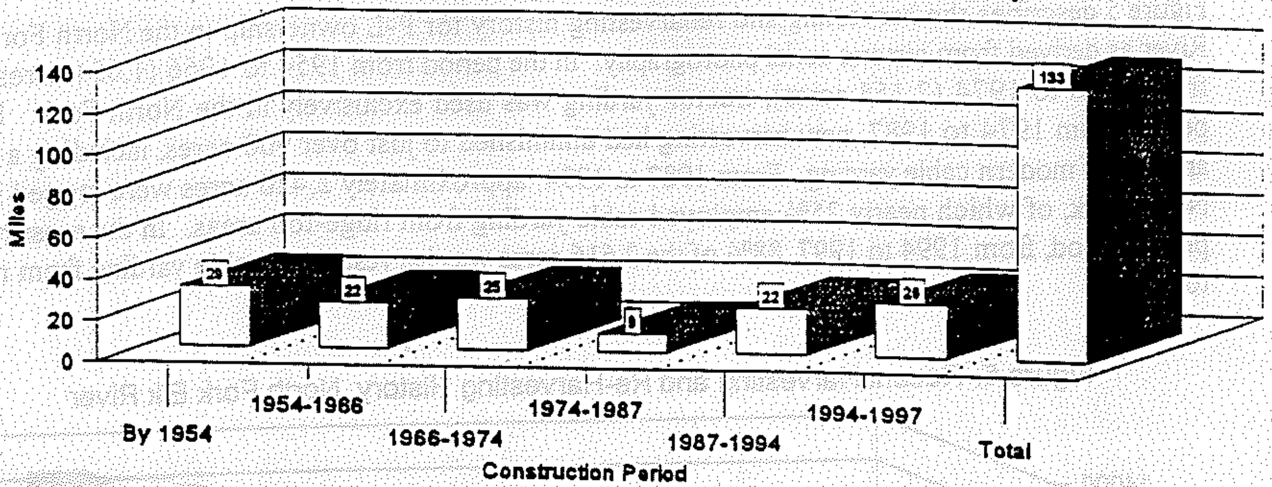
Figure 5 describes the harvesting and reharvesting history for P-L ownership in the North Fork Elk River as derived from historic aerial photography. In the period from 1954 to 1966 (1,054 acres) and from 1966 to 1974 (2,155 acres), tractor yarding was used exclusively in the North Fork. In the period from 1974 to 1987, new harvesting had diminished to just over 900 acres, including a small amount of modern cable yarding. From 1987 to 1994, approximately 2,420 acres were logged in the North Fork, of which nearly 25% employed cable yarding from ridge-top areas. In the most recent photo period, from 1994 to 1997, 88% of the 2,616 acres was harvested by cable yarding from ridge-top areas.

Figure 5. Recent Harvesting and Re-Harvesting History, North Fork Elk River



The first "roads" built in the watershed were those routes used for the railroads. Old railroad grades can be found throughout the North Fork Elk River basin. They include both ridge routes, some mid-slope routes, and alignments which paralleled the major stream channels in the valley bottoms. Most large stream channel crossings employed trestles rather than fills, so impacts of direct sedimentation at large crossings were minimized. Early harvesting involved construction of rail road grades along the main channel and up alongside several of the larger lower-basin tributary streams, as well as ridge top grades along the northern perimeter of the basin.

Figure 6 and Map 2 depict the general road construction history for the North Fork Elk River, as derived from an analysis of aerial photography. Construction of logging roads in the North Fork paralleled the advent of tractor yarding, because the same machines were used for both activities. By 1954 (the date of the first photography available for the entire watershed), approximately 29 miles of logging haul road had been constructed within the North Fork Elk River study area. Some of the main truck roads in the watershed now occupy the old railroad grades. These early roads took advantage of the previous excavations and low or moderate grades of the rail routes. Thus, the bulk of this early road building incorporated previous rail road alignments in the valley bottom from the mouth of the North Fork upstream to the easterly watershed divide. Additional construction was



localized in the North Branch North Fork where spur roads were built alongside and within the riparian zones of third order tributary streams.

Between 1954 and 1966, 8% of the North Fork study area was logged and approximately 22 miles of additional haul road was constructed (Figure 6). Most of the lower watershed had been logged in the early part of the century, so virtually no new roads were constructed for logging in the lower two-thirds of the watershed below the South Branch North Fork. Most new road construction in the 1954-1966 period occurred along the upper North Fork, the South Branch North Fork and the middle North Fork above the South Branch confluence. Many of the roads built during this period can be characterized as lower slope and stream side main line roads. Additional construction was again localized in the North Branch North Fork where spur roads were built alongside and within the riparian zones of several second and third order tributary streams. Many of these early secondary routes have since been abandoned.

In the eight year period from 1966 to 1974, 25 miles of road was constructed in the watershed. Most of the roads built during this period are located in the Lake Creek sub-basin and the South Branch North Fork. These routes are generally spur roads that were used to enter portions of the watershed for first entry logging of old growth. Rates of logging and road construction diminished substantially during the 13 year period from 1974 to 1987. During this period, just over 900 acres were logged and only 9 miles of new road was built. New roads were located principally in the northeastern and southeastern parts of the basin, as well as several spur routes lower in the watershed in Browns Gulch and Bridge Creek.

Logging and road construction again picked up in the two time periods from 1987 to 1994 and from 1994 to 1997 (Figure 6). Roads built from 1987-1994 include midslope roads accessing residual old growth in the northeastern and southeastern headwaters of the North Fork, a long ridge road along the northern divide with Freshwater, and a ridge road and spur road system down the eastern margin of Bridge Creek. The 1994 ridge roads were the first of a number of more recent roads built along ridge top areas in the middle and lower watershed to provide access for cable logging of advanced second growth forests which had first been logged in the 1920s and 1930s.

The North Fork Elk River watershed is typical of a number of coastal basins where early logging removed the old growth forest but truck roads were not constructed over much of the area until second growth forests were entered. For this reason, logging road construction has continued, and even accelerated in recent years, as these areas are opened for harvesting. Similarly, harvesting of the last remaining old growth stands in the upper watershed was occurring essentially simultaneously with the beginning of harvest operations on second growth areas in the lower watershed. Most of the 26 miles of new road constructed between 1994 and 1997 in the North Fork Elk River occurred in the lower and middle portions of the watershed to provide access to areas containing second growth ranging in age from approximately 65 to 110 years in age, and patches of residual old growth. Unlike many of the roads constructed prior to 1974 that followed alongside stream courses, new roads built in the middle 1990s largely consist of main line ridge roads and short spurs built on tributary ridges to provide access for cable yarding.

Storm history, land use and erosion

As with most other watersheds in north coastal California, flood events in Elk River have been the triggering events for landsliding and road-related fluvial erosion. Regional flood histories which would be applicable to the North Fork Elk River watershed have been described by Harden (1995), Coghlan (1984) and Helley and LaMarche (1973). A number of large flood producing storms occurred in the late 19th century and these are thought to have been comparable to, or larger than, those of the period 1953 to 1975. These include the "unprecedented" floods of 1861-1862 (Harden, 1995), as well as major events in 1867, 1879, 1881, and 1888. North of the Eel River, the 1890 flood is thought to have exceeded the magnitude of the 1964 event.

In the 20th century, flood events recorded in the north coast area in 1907, 1915, 1927, and 1937 were locally significant but did not match those in the 1950s and 1960s (Coghlan, 1984). Flood events of 1953, 1955, 1964, 1972, 1975, 1986 and 1996 appear to have been higher and produced greater watershed response than those in the first half of the century. The storms of 1953 and 1972 were centered north of the Eel and produced only moderate runoff events. The 1955, 1964 and 1975 storms tracked over the lower Eel and produced substantial rainfall (16", 15" and 9", respectively, at Scotia)[1]. The magnitude of the storm events of the late 1990s were locally extreme, even in comparison to other storms or record. Preliminary data from the USGS gaging station on Bull Creek in the lower Eel River basin is preliminarily ranked as the storm of record, surpassing even the "legendary" flood events of 1955 and 1964 (Cafferata, written communication, 12/10/97).

Stream discharge records for Elk River were only collected by the USGS for an eleven year period, from 1957-1967, so no documented discharges are available for the more recent flood events. Local

[1] Any large storm produces considerable speculation as to the magnitude and recurrence of the event, and the 1964 storm and flood is a prime example. Studies of alluvial stratigraphy place these events in a longer term perspective than short term stream discharge records. Stratigraphic studies of 1964 flood deposits (Helly and LaMarche, 1973; Kelsey, 1980; Zinke, 1981) suggest the 1964 flood event had a recurrence interval of 60 to 80 years.

residents have observed floods of note in the lower watershed in December, 1955, December, 1964, January 1974, and more recently in December 1995, December, 1996, and January, 1997 (Cafferata, written communication, 12/10/97). Based on comparisons, with the Bull Creek watershed, and from local observations, Cafferata concludes that "it is likely that smaller, lower elevation watersheds such as Elk River were recently stressed by a runoff event at or above the highest that occurred in the past 40 to 50 years." The conclusion is that one or more of the most recent storms were more intense than those of either 1955 or 1964.

Where discharge records are lacking, precipitation records for nearby stations can provide additional information on the potential geomorphic significance of storm events in the watershed. The nearest upper elevation station to the North Fork Elk River watershed is at Kneeland, California. It is located approximately two miles northeast of the headwaters of the North Fork Elk River on Kneeland Ridge. Hourly precipitation totals have been collected for 46 of the last 48 years. At the time of his analysis, Cafferata (written communication, 10/31/97) has indicated that the 24 hour precipitation total of 11.03 inches for December 30, 1995 was higher than for any other date on record, greatly exceeding the second highest daily total of just over 6.0 inches which occurred in 1955. The 1996-97 one day maximum of 5.35 inches appears to have been the seventh highest of record, and had a recurrence interval of under 10 years.

Conroy (1998) has prepared an analysis of storm event rainfall applicable for Freshwater Creek and Elk River watershed areas based on records from the Kneeland station. In the analysis, he defined storm events as continuous periods of rainfall in which daily precipitation totals exceeded 0.1 inch and event totals were at least 4 inches. Breaks in the record with lower values of accumulated daily precipitation were assumed to allow sufficient time for significant flood recession. The Kneeland station experienced 46 storm events, as defined by this analysis.

Using Gumbel Type 1 Extreme Value analysis, the storm events of January and December, 1996 had recurrence intervals of 41 and 47 years, respectively (Conroy, 1998). According to Conroy, residents in lower Elk River "observed flood flows in December 1996 greater in magnitude than any other year. The storm event that resulted in this flood had the third highest recurrence interval of all storm events of record at the Kneeland, California weather station (Conroy, 1998, p. 2). The earlier December, 1995 storm ranked number 25. Although records for the January 1997 storm were not yet available for the analysis, the state climatologist has indicated that the 1997 storm was "one of the three largest storms in the last 50 years" (Conroy, personal communication). Clearly, the storm events which occurred within the 1994 and 1997 assessment interval used in the Elk River sediment source analysis were historically and geomorphically significant, in comparison to those of either 1955 or 1964. This three year period contained three of the largest storm (precipitation) events in the last 40 to 50 years.

The erosional response of the North Fork Elk River to the floods of the 1900s appears to be a complex function of storm magnitude, geomorphic sensitivity and land use history. Photos of early logging of nearby watersheds show substantial disturbance to stream channels. Early logging resulted in channel filling, very large expanses of clearcut terrain and virtually no protection of stream channels. Over half of the North Fork watershed had already been logged by the time of the 1955 storm and flood. Some second growth stands in the lower watershed were already 70 years old.

Erosion in the watershed consists of a combination of both persistent fluvial erosion and episodic processes. Persistent processes occur every winter, regardless of the occurrence of high magnitude storms. Storm events increase the rate of these fluvial processes, some of which are management-related. For example, from the 1940s through the 1970s extensive tractor logging was conducted in the watershed and low order stream channels were commonly used as skid trails for skidding logs downslope to newly constructed truck roads. These "tractored" stream channels were filled with soil and organic debris during yarding operations and this material has been slowly eroding and moving down the channel system. Small stream channels have limited stream power and the process of scouring and transporting stored sediment is a persistent process that has been occurring for decades and will continue to deliver sediment to the channel system for decades to come. It is a management-related sediment source that is not readily amenable to cost-effective treatment.

In contrast to persistent processes, episodic erosional processes consist of both hillslope landslides (both management-related and "natural") and road-related mass wasting and fluvial processes (stream crossing washouts and stream diversion gullies). These processes are triggered by large storms. The greatest number of hillslope landslides in the North Fork watershed occurred during photo intervals containing the largest storms (especially 1966 and 1997), but new landslides were also observed for each of the other photo intervals. The 1955 and 1964 storms triggered widespread landsliding in many watersheds of the northcoast, including the North Fork Elk River, and this high rate of slope failure is thought to be the combined result of high intensity storms and the slope-weakening effects of harvesting (Kelsey et al., 1995). Severe storms, such as those in 1955, 1964, 1996 and 1997, are the triggering events for these geomorphic changes.

Sediment sources

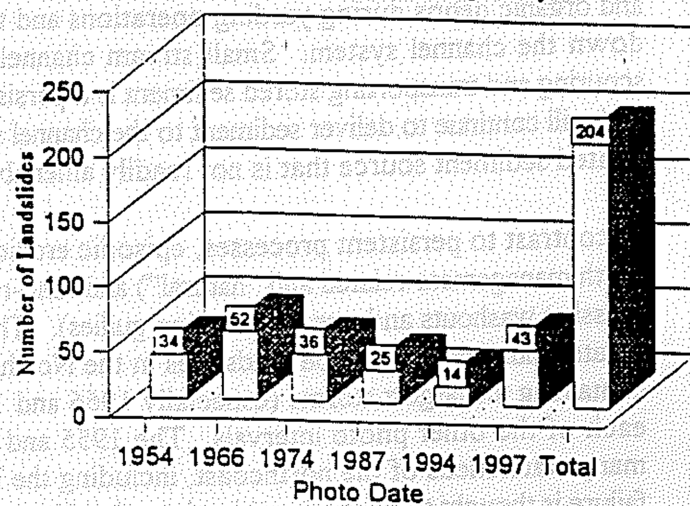
Sources of sediment in the North Fork Elk River watershed include mass wasting (deep-seated landslides, shallow-rapid debris landslides, and debris torrents), fluvial erosion (gullying, channel erosion, and stream bank erosion) and surface erosion. The sediment source investigation included data from three investigation techniques designed to identify the frequency and general magnitude of both fluvial erosion and mass wasting processes in the basin. Each technique provided unique data that, when combined, produces a picture of the magnitude of major mechanisms of sediment production and yield in the North Fork Elk River watershed.

Mass wasting

An aerial photo analysis was employed to identify large landslides, debris torrents, bank erosion and channel aggradation that could be identified from 1:20,000 (1954) and 1:12,000 scale images (remaining years). The minimum measurement resolution for features identified on the photos was approximately 35 feet (1954) and 20 feet (all other photo years). The oldest images evaluated were taken in 1954. By that time, over half the watershed had already been logged (Figure 3).

Landslide frequencies for each of the photo periods are shown in Figure 7. Analysis of the 1954 aerial photos revealed 34 "new" landslides in the watershed, most of which were assumed (because of the degree of revegetation of the slide surfaces) to have occurred sometime within the previous 15 to 20 year period (Figure 7 and Map 3). Landslide frequencies in the North Fork Elk River were highest in photo years 1966 and 1997; both periods containing one or more locally significant storms (1955, 1964; 1997, respectively).

Figure 7. Landslide Frequency



Landslide rates (#/yr) can be calculated using the intervals portrayed by each photo period (Table 1). As might be expected, rates of landsliding generally rise and fall with the occurrence of storms in the watershed. Thus, the highest rates of landsliding (#/yr) occurred during photo intervals containing major storms (1966, 1974, 1997).

Land use activity, including both harvesting and road construction, was reduced during the 1966 photo period, yet two major storm events (1955 and 1964) triggered an increase in landslide frequency. Increase rates of road building and harvesting from 1966 to 1974, as well as locally significant storms in 1972 and 1973, were associated with continued elevated rates of landsliding (Table 1).

Landslide rates then dropped during the next two relatively "storm-free" photo periods (1987, 1994). Finally, the storms of January 1996, December 1996 and January 1997 triggered a large increase in landslide rates in the North Fork (Table 1). Some of this increase may be associated with increases in land use activity (both road building and harvesting) during the same period, but a great deal is liklely associated with the magnitude and frequency of major storms during the three year period. The short time interval of measurement (1994-1997) also magnifys the apparent effect of the triggering storms in comparison to other periods of analysis (1954-1966, 1966-1974, 1974-1987 and 1987-1994) which average over 10 years in length. If the measured time interval is spread out to include data from the period 1975 to 1997 (thereby including two relatively storm-free periods), the landslide rate falls to 3.6 landslides/year.

Landslide distribution and sediment delivery

Landslide distribution in the watershed is dependent on a number of factors, including underlying geology and soils, hillslope gradient, geomorphic position, land use activity and localized precipitation intensity. Landslides in Elk River are generally concentrated on steep streamside slopes and steep swales throughout the watershed (Map 3). Rapid rates of uplift in the basin, combined with erodible bedrock, has resulted in rapid channel incision and steep headwater areas in a number of sub-basins. Geologic and geomorphic mapping (CDMG, 1985) has identified many hillslopes as being

Table 1. Land management and landslide rates for six photo periods, North Fork Elk River

Photo date	Road building rate (mi/yr)	Harvesting rate (acres/yr)	Landslide rate[1] (#/yr)
1954	1.9	162	1.7
1966	1.8	88	4.3
1974	3.1	269	4.5
1987	0.7	72	1.9
1994	3.2	345	2.0
1997	8.8	872	14.3[2]
Total	2.1	197	3.2

[1] Landslide rates are dependent on landslide frequency (#) and duration of measurement interval. All else equal shorter intervals generate higher rates.
[2] Roughly half of the 1997 landslides occurred on areas harvested prior to 1994. Fourteen of 24 landslides identified on areas harvested between 1994 and 1997 occurred on two harvest units in the lower basin.

formed by repeated debris sliding (characterized as "debris slide slopes"). These debris slide slopes are characterized by steep ridge and swale topography.

Landslide location in the North Fork Elk River watershed is at least partially dependent on the geologic type of the underlying substrate. Five landslides were identified as occurring on steep streamside and inner gorge slopes of unconsolidated Quaternary terrace deposits in the lower watershed with the total delivery of less than 1,000 yds^3. Most of the terrace surfaces are flat or low gradient and have a low landslide potential except where streams have downcut through, or laterally undercut, the poorly consolidated materials. Average landslide volumes are less than 700 yds^3 with only 185 yds^3 of unit sediment delivery (26% delivery rate).

Slopes underlain by Franciscan geologies in the extreme upper basin experienced 20 landslides during the period from approximately 1934 to 1997. Most of these were located along inner gorge and steep stream side slopes. Landslides on Franciscan terrain delivered an estimated 32,800 yds^3 of sediment to the stream system during the period of record. A single landslide and torrent originating in a steep headwater swale accounted for about half of this volume. Franciscan landslides average just over 4,000 yds^3 in volume with just 1,600 yds^3 of sediment delivery (40% delivery rate).

Landslides on terrain underlain by rocks of the Yager formation are most common along steep inner gorge slopes along the main channel and major tributaries in the upper basin. This is largely because Yager geologies are exposed almost exclusively in stream side areas of the upper basin where channels have downcut through the thin Wildcat formation to expose the underlying Yager rocks (see Map 3). Landslides in Yager terrain are the largest in the North Fork watershed, averaging over 3,600 yds^3 in volume and delivering nearly 2,000 yds^3 to the stream system (56%). High delivery rates are likely due to their common occurrence on steeper stream side and inner gorge slopes.

Finally, 136 landslides were documented to have occurred on terrain underlain by the Wildcat group of rocks. These 136 landslides produced an estimated 502,000 yds^3 of erosion but delivered only 179,000 yds^3 to the stream system (36% delivery rate). Average unit volume and yield for Wildcat landslides was 3,700 yds^3 and 1,300 yds^3, respectively. In contrast to inner gorge landslides in Yager terrain, a larger number of Wildcat landslides originated farther up slope in steep swales. In the North Fork Elk River watershed, landslides which developed high on the hillslope were less likely to deliver a large proportion of their material to a stream channels. Small landslides were also less likely to yield large percentages of their failure materials to stream channels.

Estimated sediment delivery for landslides in the North Fork watershed ranged from a low of 18% for landslides appearing during the non-storm period of 1974 to 1987, to a high of 47% for landslides triggered during the two periods with the largest storms (1954-1966 and 1994-1997). Clearly, storm magnitude appears to have influenced the delivery efficiency of landslides. Slides forming in response to the largest storm events were generally larger and had the greatest estimated unit sediment delivery. Slides which formed during the 1987-1994 period were the smallest of all the inventoried landslides.

Landform Associations with Mass Wasting

In all years of analysis, the majority of debris landslides (69%) occurred within steep inner gorge slopes, including steep swales within the inner gorge (Table 2). Inner gorge slopes are here defined as slopes that are steeper than 65% which occur below the last (lowest) significant break-in-slope next to a stream channel. For this study, streamside slopes occupy the same slope positions, but occur on slopes less than 65%. Table 2 lists the geomorphic associations, and landslide frequencies, for each of the photo periods analyzed.

Inner gorge (>65%) and stream side (<65%) slopes were the most common point of origin for landslides identified in the air photo inventory. Inner gorge landslides were four times more common than streamside landslides but average unit volumes were 2.5 times less (Table 3). Inner gorge landslides from 1994 were considerably smaller, in both length and volume, than were similar slides from the other time periods. The average length of inner gorge and stream side landslides for the period of record was 200 and 310 feet, respectively. Several large landslides observed on the 1954 aerial photos skewed the average dimensions and volumes for stream side landslides during that time period.

Table 2. Landform associations with mass wasting, North Fork Elk River watershed

Photo Year	Inner gorge[1]	Streamside	Swales and Headwalls	Break-in-slope	Total number of slides
1954	26	7	0	1	34
1966	36	10	4	2	52
1974	28	4	3	1	36
1987	12	10	3	0	25
1994	10	2	2	0	14
1997	34	4	2	3	43
Total	**132**	**33**	**14**	**7**	**204**
Percent of Total	**69%**	**13%**	**9%**	**5%**	**100%**

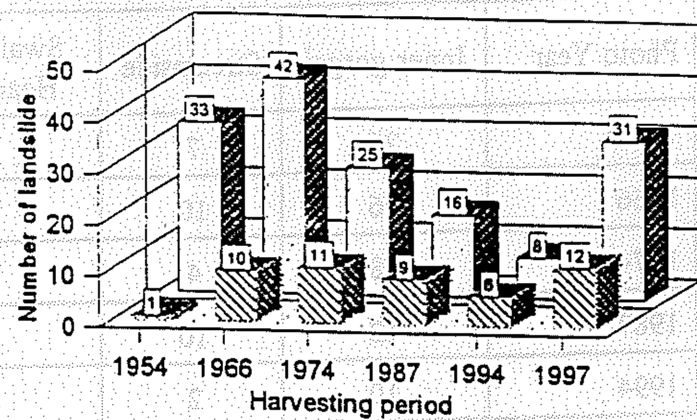
[1] Includes steep swales located within the inner gorge. For example, of the 34 inner gorge landslides identified on 1997 aerial photos, 15 occurred on steep inner gorge swales.

Table 3. Frequency, length and volume of inner gorge and streamside debris slides, North Fork Elk River

Photo year	Number of IG landslides	Length (ft)		Average volume (yds^3)	Number of streamside landslides	Length (ft)		Average volume (yds^3)
		Avg	Max			Avg	Max	
1954	26	330	855	3,500	7	650	1,650	20,500
1966	33	185	510	4,500	9	390	990	6,500
1974	21	140	310	2,300	4	125	180	1,100
1987	10	100	230	900	9	70	155	400
1994	9	55	90	300	0	--	--	--
1997	33	230	660	1,900	4	265	770	4,200
Totals	**132**	**200**	**855**	**2,744**	**33**	**310**	**1,650**	**6,900**
Average yield (yds^3)				**1,200 (44%)**				**2,400 (35%)**
Total yield (yds^3)				**159,000**				**78,000**

Land use associations with mass wasting
The distribution of landslides inventoried in the North Fork Elk River watershed, with respect to land use, is shown in Figure 8. Of the 204 landslides mapped in the air photo inventory, 24% were identified as "road-related." The remaining 76% were classified as "hillslope landslides." Average landslide volume for road-related landslides (3,770 yds^3) compared closely with average hillslope landslide volumes (3,600 yds^3). Mean sediment delivery was estimated to be approximately 40% for both road-related and hillslope landslides.

Figure 8. Land Use and Landslide Associations



Data from the aerial photo analysis can be viewed in several ways to suggest how land management may have altered landslide processes in the North Fork Elk River watershed. Because logging had commenced early in the North Fork (1880s), very little of the watershed was still unlogged by the time the first aerial photos were taken (1954). Thus, it was not possible to identify more than a few pre-logging landslides in the North Fork watershed from the earliest photos.

Large landslides - Several factors, such as storm magnitude, elapsed time since the last storm event, seismic history, geologic types, hillslope steepness and watershed condition, are likely to affect the geomorphic response of the landscape to a large storm event. Watershed response might be expressed in landslide frequency and size, as well as torrent track formation and the development of enlarged or aggraded channels[2].

Figure 9. Distribution of landslide lengths

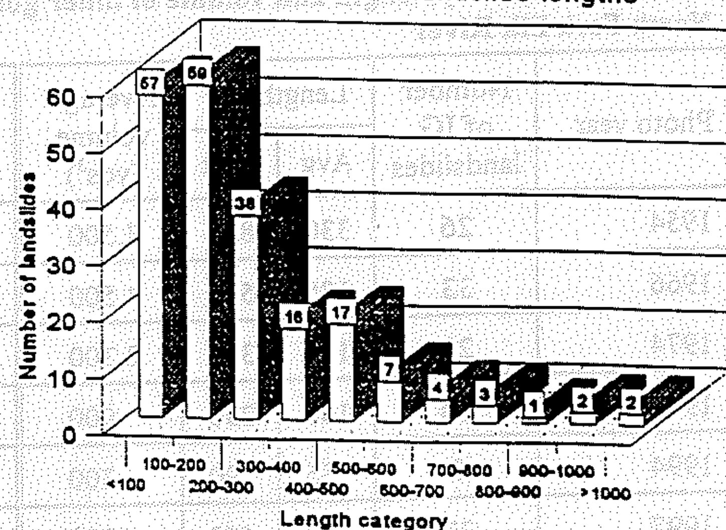


Figure 9 identifies the distribution of landslide lengths within the study area. Seventy-five percent of the landslides inventoried were less than 300 feet in

[2] Enlarged channel reaches are those in which riparian vegetation is damaged or lost and canopy openings along low gradient stream channels become apparent on aerial photos.

length. However, 19 landslides (10% of total) identified in the aerial photo analysis exceeded 500 feet in length, including the depositional zone. These accounted for approximately 50% of the total sediment delivered from all landslides during the study period.

In some northcoast watersheds, a relatively small number of large landslides produce a substantial portion of the total sediment yield from all mass movement features. In the Bear Creek watershed of the lower Eel River, large landslides were found to have occurred in both the pre-management and post-management period (PWA, 1998). Large landslides (>5,000 yds^3) were found to account for at least 65% of the sediment delivered to stream channels from all landslides. Similar relationships between landslide size and contribution to total landslide sediment yield were published by Kelsey et al. (1995). In an analysis of stream side landslides in the Redwood Creek basin (northern Humboldt County) they found that the largest 10% of the landslides accounted for 60% of the total landslide volume. The largest 15% of landslides, by number, contributed nearly 80% of the landslide contribution to sediment yield. Similarly, the smallest 50% of the inventoried landslides, by number, contributed only 5% of the total landslide volume.

The largest debris landslides which have been identified for each of the six photo dates in the North Fork Elk River were divided into volume classes for comparison: 1) large: 3,000 to 5,000 yds^3, and 2) very large: >5,000 yds^3 (Table 4). Twenty-three landslides (11% of the total number) identified in the North Fork Elk River had an estimated sediment delivery exceeding 3,000 yds^3. These 23 slides accounted for 68% of the total sediment delivery from all landslides for the period from 1954 to 1997. In contrast, the 181 landslides that were smaller than 3,000 yds^3 accounted for 89% of the North Fork landslides (by number) but only 32% of the total sediment delivery from mass movement during the period of record.

Significantly, very large landslides (>5,000 yds^3) occurred in North Fork Elk River during only three photo periods (1954 (n=3), 1966 (n=7) and 1997 (n=2)). Without triggering storms, very large landslides are very uncommon (or absent), and even with large events, landslides exceeding 10,000 yds^3 in delivery volume (which were common and highly important in Bear Creek) are relatively uncommon in the North Fork Elk River watershed. Only five landslides potentially fall into this category (>10,000 yds^3) in the North Fork watershed (1954, n=1; 1966, n=3 and 1997, n=1). The single 1997 landslide in this category was road-related and actually occurred in 1996, the year before the 1997 storm.

There is little indication from the aerial photo analysis that large and very large landslides occur in unique settings in the North Fork Elk River watershed, as compared to smaller, more common landslides. That is, aside from their occurrence in lower and streamside slopes, large landslides do not appear to occur in any particular location or are associated with any particular land management practices. Analysis of aerial photography indicates that these large landslides occur on both streamside (50-65%) and inner gorge (>65%) slopes, and that they are associated with all management practices (roads, partial cuts, clear cuts and advanced second growth) and ages of harvest (<15 years and >15 years). They develop on slopes from 40% to 75% in steepness, with an average initiation gradient of between 50 and 60 percent. Such slopes (>50%) are very common in the watershed, covering over 40% of the landscape of the North Fork (Figure 2).

Table 4. Large landslide frequencies and contribution to mass wasting sediment yield for six time periods, North Fork Elk River

Photo Date	Watershed condition	Large Debris Landslides 3,000 - 5,000 yds^3		Very Large Debris Landslides > 5,000 yds^3		Large and very large landslides (% of total yield from all landslides)
		No.	Total delivery (yds^3)	No.	Total delivery (yds^3)	
1954	Early steam donkey & railroad; Pre-FPR truck roads and tractor logging	5	18,000	3	49,000	23%
1966	Pre-FPR tractor yarding and road construction; 1955 and 1964 storms.	2	7,000	7	87,000	32%
1974	Largely Pre-FPR tractor yarding and road construction; Moderate 1972 storm.	1	4,000	0	----	1%
1987	Post FPR; Reduced harvesting and road building; Moderate 1975 storm	0	----	0	----	0%
1994	Post-FPR; Increased cable yarding and ridge road construction.	0	----	0	----	0%
1997	Post-FPR; Increased harvesting, mostly cable yarding. New ridge road building; 1997 storm	3	12,000	2	25,000	12%
TOTAL		11	41,000	12	161,000	68%

Road-related landsliding - As might be expected, road-related landslide frequency shows peaks that correspond with storm periods. A total of 49 road-related landslides were identified in the aerial photo inventory. Just over 80% of the estimated sediment delivery from these sites originated from 22 sites during the 1966 (36% of volume) and 1997 (46% of volume) photo periods. The length of roads in the watershed has steadily increased throughout the entire period of record. Approximately

50 miles had been constructed by 1966. By 1997, over 130 miles of road was in existence on P-L lands in the watershed. One road-related landslide was triggered for every five miles of existing road in 1966.

In the 1997 period, landslide frequency had dropped to one slide for every 11 miles of road in the watershed. Although frequencies dropped for a variety of reasons (better construction; better location (ridges); many susceptible sites had already failed, etc.), total road-related landslide delivery to the stream system still increased. Significantly, very few of the 1997 landslides originated from ridge roads that had been constructed during this accelerated period of road construction. Instead, most failures developed on older roads in middle and lower hillslope positions.

Harvest associations - Regardless of the analysis period, hillslope landslides (non road-related) in North Fork Elk River were more common than road-related slides. During the 1966 photo period, large landslides (those that show up on 1:12,000 scale aerial photography) were about 4 times more common on non-roaded hillslopes than along roads (Figure 8). In 1997, hillslope debris slides again outnumbered road-related debris slides by an overall margin of about 2.6:1.

Harvesting has occurred in Elk River since the 1880s. Complex cutting histories make it difficult to evaluate and separate the effects of harvesting and storm magnitude on slope failure. Both land use and storm magnitude have likely influenced landslide frequency within the watershed. Over the span of the available record (1954-1997), 76 landslides were identified on slopes which had been logged more than 15 years earlier (Table 5). These landslides accounted for approximately 98,000 yds^3 of sediment delivery and an average landslide yield of 1,300 yds^3. For comparison, 62 landslides were identified as having occurred on hillslopes that had been harvested less than 15 years earlier. Total volume of sediment delivery from these recently harvested slopes was estimated to be 96,000 yds^3, with an average unit landslide delivery volume of 1,600 yds^3.

Torrent Tracks, Bank Erosion and Enlarged Channels

Field mapping and aerial photo analysis were also employed to identify the location and magnitude of erosion along stream banks and in channels which had experienced debris torrents. In addition, air photos were analyzed for evidence of enlarged channels. Enlarged channels are defined as channel reaches which exhibited channel scour sufficient to visibly disturb or remove the riparian canopy, or concentrations of freshly deposited sediment sufficient to be readily visible on aerial photos. Enlarged channels are most likely to develop during large storm events where channels are scoured by flood flows or heavy channel deposition occurs.

Torrent tracks - Only five debris torrents were identified in the analysis of aerial photography for the North Fork Elk River watershed. All five occurred in the upper watershed and originated as debris slides on slopes ranging from 45 to 60% gradient. Debris torrents travelled for limited distances down the receiving channels. The three torrents visible on 1966 aerial photos each traveled 550 feet down the channel before coming to rest. In the 1997 photos, one torrent traveled 400 feet and the longest feature was approximately 1,650 feet long.

Table 5. Debris landslides associated with recently harvested and older harvested slopes, North Fork Elk River watershed

Photo year	Slides on >15 year old harvested slopes[1] (yds^3)		Slides on <15 year old harvested slopes (yds^3)		All non road-related landslides (yds^3)	
	No.	Volume (yds^3)	No.	Volume (yds^3)	No.	Volume (yds^3)
1954	15	64,300	12	11,400	27	75,700
1966	13	11,000	25	66,500	38	77,500
1974	21	14,600	2	300	23	14,900
1987	16	5,000	0	0	16	5,000
1994	7	700	1	400	8	1,100
1997	4	2,300	22	17,700	26	20,000
Total	**76**	**97,900**	**62**	**96,300**	**138**	**194,200**
Average slide yield		**1,300**		**1,600**		**1,400**

[1] Includes landslides in advanced second growth areas.

Sediment yield from individual torrent tracks ranged from an estimated 1,600 yds^3 to a maximum of 11,000 yds^3. In 1966, a total of 5,700 yds^3 of sediment yield was derived from the three torrent tracks. Approximately 12,800 yd^3 of sediment yield was generated from the two torrents visible in the 1997 aerial photos. Four of the five debris torrents came to rest in small first or second order stream channels where channel gradients significantly diminished. One of the torrents carried its deposits to the middle section of Doe Creek, a small third order tributary to the North Branch North Fork Elk River. The reach of Doe Creek which received the deposits was classified as an enlarged (aggraded) channel during the 1966 aerial photo analysis. None of the other torrents deposited enough sediment in downstream channel reaches to cause them to be classified as "enlarged."

Bank erosion - Field inventories were conducted along three reaches of the North Fork Elk River totaling 3.6 miles of stream channel to determine the frequency and magnitude of bank erosion. Within the main stem of Elk River, and within aggraded sections of the main tributaries (classified as "enlarged channels"), lateral channel migration during and following flood events caused local bank erosion. This process constitutes another source of sediment that is eroded and delivered to the channel system. During our field inventory, we documented and measured sites of bank erosion along selected stream reaches, and derived unit estimates of bank erosion sediment production that could be used to apply to channel reaches not visited in the field (Table 6).

Table 6. Bank erosion along sampled stream reaches, North Fork Elk River				
Reach No.	Reach Length (feet)	Length of measured bank erosion (ft)	Bank erosion volume (yds^3)	Average erosion rate (yds^3/ft)
1	6,996	2,919	4,661	0.67
2	4,198	2,127	2,021	0.48
3	7,696	2,081	2,284	0.30
Total	18,890	7,127	8,966	0.47

The three reaches listed in Table 6 are found along the main stem North Fork in the lower 8.6 miles from the lower P-L property boundary upstream to the confluence with the South Branch North Fork. Reach 1 extends from the Scout Camp a distance of 1.33 miles downstream. Reach 2 extends from the Bridge Creek confluence upstream for 0.80 miles. Reach 3 extends downstream for 1.46 miles from the South Branch confluence. As might be expected, bank erosion rates (yds^3/ft) increase in the downstream direction from a low of 0.30 for Reach 3 to a high of 0.67 for Reach 1.

Average bank erosion rates from adjacent reaches were applied to the remainder of the unsampled main channel to derive an estimate of the total contribution of bank erosion to sediment yield. Reach 3 bank erosion rates were applied to the lower 1.75 miles of the North Branch and 5.6 miles of the upper North Fork to derive an estimate for bank erosion and sediment delivery for these main channels. The resulting estimated contribution to sediment yield from bank erosion processes along major stream channels totals approximately 33,100 yds^3 since the early 1960s.

Of all 74 sites of bank erosion identified in the sampled reaches, 26 are currently inactive and 48 show signs of continuing erosion. Some bank erosion sites occur along the active channel thalweg, while others are only active during flood flows which occupy the flood plain along the channel system. Eleven sites of measured bank erosion were judged to have originated during the 1990s, and these eleven sites have yielded an estimated 1,340 yds^3 of sediment yield to the stream system. This accounts for approximately 15% of the total yield within the measured reaches. Forty-one of the 74 sites of measured bank erosion were judged to have originated in the 1960's, based on site specific evidence, including revegetation. Approximately 40% of the total measured bank erosion was derived from these older sites. Of the 41 older sites, 23 were judged to still be actively eroding.

Enlarged channels - Enlarged channel (EC) segments occur where channel deposition or erosion causes visible opening(s) in the riparian canopy. If there is no riparian canopy, enlarged channels are often characterized by substantial (visible) fresh aggradation in or along the active channel. Enlarged channel reaches in the North Fork Elk River watershed were mapped during the analysis of aerial photos. Three photo periods, 1954, 1966 and 1997, showed evidence of the development of enlarged channels.

A total of 2,300 feet of enlarged channel in two reaches was identified on the 1954 aerial photos. Both stream reaches occurred in the main channel in the upper watershed just above the confluence of the North Branch (Map 3). These two channel segments each were an estimated 70 feet wide at the time of measurement.

A total of 25,000 feet of enlarged channel was identified in 16 channel reaches from the 1966 aerial photography (Map 3). It is assumed that these reaches formed as a result of the 1955 and/or 1964 flood event, as they were not visible in the 1954 photography. Individual 1966 EC reaches ranged in length from 400 feet to 6,300 feet, with a mean length of 1,560 feet. Measured widths for these channel openings ranged from 40 feet to 180 feet, with a mean of approximately 85 feet. Another 7,100 feet of channel was characterized as displaying discontinuous canopy openings. These four reaches ranged in length from 810 feet to 2,200 feet. 1966 enlarged channels were distributed around the watershed in the lower, middle and upper mainstem, and in tributaries in both the lower and upper North Fork watershed (Map 3).

Finally, a total of 3,800 feet of enlarged stream channel was identified in nine stream reaches on the 1997 aerial photography. These enlarged channels presumably formed in response to processes operating during the 1996/97 storm event. Individual channel reaches ranged from 130 feet to 880 feet in length, with a mean length of approximately 420 feet. Channel widths ranged from 20 to 160 feet. Five of the nine reaches had narrow, 20 foot widths. The 1997 enlarged channels included two short segments in the main stem above the North Branch, one long segment in a tributary in the lower watershed (which developed in response to aggradation from a large debris slide), and a number of short segments in the lower main stem upstream and downstream from the Scout Camp (Map 3).

Other fluvial sediment production

During early stages of the field inventory, it became apparent that channel erosion in low order streams was a relatively common occurrence. Early steam donkey and oxen logging in the lower North Fork in the late 1800s, and cable yarding and railroad hauling from the 1920s through the 1950s, resulted in extensive channel filling in higher order stream channels of the lower basin. Old railroad grades are visible in, along and crossing many of the main tributaries of the North Fork Elk River. The volume of soil that was originally placed in these larger channels when the railroad grades were constructed is, at this point, impossible to determine. Regardless, these deposits have largely been scoured and flushed downstream and the main tributaries appear to have re-established generally stable profiles and cross sections along their lengths.

In the early days of tractor logging in the North Fork Elk River watershed, it was also common for tractors to yard logs directly down low order stream channels, and to construct landings within the channel system where they were crossed by truck roads. Many channels were partially or completely filled with soil and debris during three decades of tractor logging from the mid-1940s through the 1970s. In the subsequent two to four decades since the practice of channel yarding was ended, these streams have progressively scoured through and flushed a portion of these sediments down stream. Field observations suggest that mechanically filled stream channels represent a potentially large, persistent source of post-harvest erosion in these areas.

To estimate the magnitude of channel filling and scour as a source of eroded sediment in the North Fork watershed, field crews first identified the general distribution and frequency of mechanically filled channels immediately above and below logging road stream crossings. At these locations, field estimates were made as to the degree of past channel filling that had occurred, as well as the rate of re-gullying of these deposits in the intervening years. Analysis of tractor logged sites identified on the 1954, 1966 and 1974 aerial photos allowed for a more complete picture of the spatial extent of past tractor yarding that had occurred in first, second and third order stream channels.

A combined total of 9.4 mi² of the North Fork Elk River watershed showed evidence of recent and extensive tractor logging on the 1954, 1966 and 1974 aerial photos. A sample of 2.78 mi² of tractor logged land was analyzed from aerial photography to determine average stream channel density and mechanical tractor disturbance (Table 7). In the sampled area, stream channel density averaged 6.85 mi/mi² and, on average, 49% of the first, second and third order stream channels had been directly impacted by tractor yarding within the channel. First order stream channels comprised roughly 55% of the total channel network, with second and third order channel composing the remainder. Roughly 45% of the first order channels had been tractored and 55% of the higher order streams had been directly impacted by mechanical filling.

Table 7. Sediment production from mechanically filled low order stream channels, North Fork Elk River

Photo Year	Tractor logged area (mi²)	Stream channel length (mi)	Tractored 1st order channels (mi)	Tractored 2nd and 3rd order channels (mi)	Sediment Production (yds³)		Total Yield (1998) (yds³)
					1st order	2nd and 3rd order	
1954	4.38	30.0	7.13	7.45	26,200	16,400	42,600
1966	1.65	11.3	2.68	2.81	9,900	6,200	16,100
1974	3.37	23.1	5.49	5.74	20,200	12,600	32,800
Total	9.40	64.4	15.3	16.0	56,300	35,200	91,500

Derived rates of erosion and sediment yield from eroding, mechanically filled stream channels is depicted in Table 7. It is estimated, from this analysis, that over 91,000 yds³ of sediment has been introduced to the stream system over the period of years covered by the three photo periods (roughly, late 1940s through 1974). These photo periods largely covered the years when tractor logging was at its most intense in the North Fork watershed, and the practice of yarding down stream channels was still a widely used technique.

Road-related sediment sources

As the third phase of the sediment source investigation, a 100% field inventory was conducted to identify and measure sediment production and sediment delivery from road-related sediment sources throughout the North Fork Elk River watershed. A total of 133 miles of road was inventoried, including maintained roads, old abandoned routes, and a number of ridge roads built within the last several years.

At the time of the inventory, roads were classified as either maintained, abandoned (but driveable), abandoned (not driveable) and decommissioned. Approximately 62% of the road network in the watershed (82 miles) was categorized as maintained and 35% (46.5 miles) had been abandoned. Many of these unmaintained roads had been abandoned for several decades, or longer. Less than two percent of the road network fell into the remaining categories; unmaintained but driveable, and decommissioned.

Every site of past erosion which delivered sediment to a Class I, II or III stream channel was included in the inventory. The dimensions of each erosion feature was measured, a volume was calculated, and an estimated sediment delivery rate (%) was estimated. In many cases, gullies and fill slope failures along the roads had to be traced hundreds of feet downslope through dense vegetation to accurately determine their volume and sediment delivery ratio.

Table 8 summarizes road-related sediment yield from the 133 mile road system in the North Fork Elk River, excluding the persistent contribution of fine sediment from road surfaces and ditches. A total of 602 sites were mapped in the field where past road-related sediment yield had occurred. The data has been segregated according to estimated decade in which the erosion was initiated (based on revegetation of the eroded area) and location of the erosion. Because it is difficult to identify sites which have failed more than one time in the past (road reconstruction often masks these sites), such as washed out stream crossings, gullied road beds and failed road prisms, these volumes of past erosion and sediment delivery should be considered a minimum estimate.

Likewise, we have not quantified the volume of fine sediment delivered to stream channels associated with surface and rill erosion along cutbanks, road beds, ditches and skid trails throughout Elk River. Sediment reduction techniques and prescriptions for controlling the fine sediment discharge from roads and ditches is addressed in the erosion prevention implementation plan. However, in light of the large volumes of sediment delivered by both mass wasting and fluvial erosion outlined in Table 8, as well as inner gorge and stream side landslides described earlier (Table 3), we estimate that road-related surface erosion processes account for no more than five percent of all sediment production and delivery in the watershed.

A total estimated erosion volume of 151,200 yds^3 was measured from P-L road-related sediment sources in the North Fork Elk River watershed from the 1950s to the 1990s (Table 8). Of this volume, 56% was estimated to have been delivered to the stream channel system. Sediment yield from the road system mirrored the occurrence of the major flood producing storms in the basin, with the greatest volumes of erosion and sediment delivery occurring during the decades of the 1960s and

Table 8. Road-related erosion and sediment delivery (to stream channels), by decade and erosion process, North Fork Elk River watershed

Decade	# Sites	Stream crossing washout (yds³)	Gullies (fillslope/ hillslope/ road) (yds³)	Streambank & channel erosion (yds³)	Fill Failure (yds³)	Cutbank Failure (yds³)	Hillslope Failure (yds³)	Total road-related past erosion (yds³)	Total road-related past delivery (yds³)
1950	29	840	2,160	3,494	2,560	0	1,097	10,151	9,591
1960	146	5,889	9,322	3,203	5,606	318	1,933	26,271	22,610
1970	105	4,881	4,790	2,097	1,934	0	6,747	20,449	13,701
1980	83	1,195	2,462	568	4,647	0	74	8,946	6,910
1990	239	2,144	5,677	826	22,501	975	53,245	85,367	32,497
Total road-related past erosion (yds³)	**602**	**14,949**	**24,411**	**10,188**	**37,248**	**1,292**	**63,096**	**151,184**	**85,309**

1990s. Unit sediment delivery rates for each period were 450 yds³/mi for 1966 and 244 yds³/mi for the 1997 photo period. Erosion volumes for 1997 are spread over 133 miles of existing road whereas volumes for the 1966 period are spread over a much shorter 50 mile road network that existed at that time.

As a process, mass movement accounted for 67% of the erosion identified along the road system (Table 8). A total of 120 past road-related landslides were identified and inventoried for a total past erosion of 101,640 yds³ and a yield to stream channels of 37,800 yds³ from approximately the late 1940s until 1998. Over 40% of the slope failures occurred on inner gorge slopes where roads approached stream crossings along deeply incised tributary channels, and 35% occurred on the lower gradient (50-65%) stream side slopes. Fluvial processes accounted for the remaining 49,500 yds³ of erosion and 47,500 yds³ of past road-related sediment delivery (Table 8).

Stream diversions at logging road stream crossings was the single largest component of road-related fluvial erosion and yield. Just over 60% of the fluvial erosion was attributed to stream diversion gullies occurring outside of stream crossings sites. Of the 335 existing stream crossings along the road system, 185 (55%) exhibit a diversion potential and 81 of these (44%) have diverted at least once in the past. These diversions created hillslope gullies that produced over 24,400 yds³ of erosion and sediment delivery. Stream crossing failures (washouts) accounted for 37% (14,900 yds³) of past erosion and sediment delivery from roads in the Elk River watershed. The number and volume of erosion from stream crossing wash-outs are certainly underestimated because of the masking effects of subsequent road reconstruction at past failure sites[3].

Sediment Production and Delivery from the North Fork Elk River Watershed

The three elements of the sediment source investigation included: 1) an air photo analysis of landslides and torrent tracks; 2) a field sampling of bank erosion and scouring of mechanically filled stream channels; and 3) a field inventory of road-related sediment sources. Table 9 summarizes the delivery of sediment from measured sediment sources within the North Fork Elk River watershed.

Total measured sediment delivery to the North Fork Elk River channel system from the 60+ year period of record (mid-1940s to 1997) is estimated at approximately 508,400 yds^3. This represents an average yield of approximately 550 tons/mi^2/yr. Landslides (exclusive of road-related slides measured during the road inventory) are the most important source of sediment in the basin, comprising an estimated 55% of the total volume of material delivered to stream channels during the period of record. Of the total volume of landslide material delivered to streams within the study period, approximately 20% occurred in the latest photo period (1994-1997) and 43% occurred in the 1954-1966 period.

The data clearly suggests that major storms are triggering mechanisms for landslide inputs to the channel system in the North Fork Elk River watershed. Landslides comprise over 50% of the measured sediment delivery to the stream system during the 1954, 1966 and 1997 photo periods. For the two periods containing the largest storms (1966, 1997), debris landslides and torrent scour represent approximately 70% of the sediment delivered to the stream system from all measured sources during the photo period. The high volume of landslide delivery in the pre-1954 period (landslides delivered about 82% of total sediment from all sources during that period) likely stems from the large amount of the watershed which had been harvested in the preceding 20 to 30 years (most of it by clearcutting and steam donkey yarding). In contrast, photo years with a general absense of large storms (1987 and 1994) had relatively few landslides, and these landslides accounted for and estimated 15% and 5%, respectively, of the total sediment delivery to streams during these periods.

Although infrequent, large magnitude storms (such as 1997) are driving mechanisms for watershed sediment production and change in both watersheds, the estimated rates of sediment delivery in the North Fork Elk River basin (550 tons/mi^2/yr) are still substantially lower that high yield basins such as Bear Creek (6,200 tons/mi^2/yr) over the same time period. This is likely a function of significant differences in topography and geology (as well as other factors), which control both the extent and sensitivity of potentially unstable inner gorge slopes.

Within the North Fork watershed, unit rates of sediment delivery vary from one photo period to the next (Table 10). One of the controlling variables in determining unit erosion rates and sediment

[3] Estimates of road-related erosion should be viewed as minimum values. Actual sediment yield values could be 10 to 50% higher.

Table 9. Recent sediment delivery to streams in the North Fork Elk River watershed[1]

Air photo year or decade[2]	Debris landslides[3] (yds³)	Torrent track scour (yds³)	Bank erosion[4] (yds³)	Scour of filled channels[5] (yds³)	Road-related erosion[6] (yds³)	Total sediment delivery (yds³)	Percent of total
1954 (50s)	80,900	0	--	8,000	9,600	98,500	19%
1966 (60s)	121,500	5,700	15,200	14,200	22,600	179,200	35%
1974 (70s)	23,300	0	9,600	17,800	13,700	64,400	13%
1987 (80s)	6,800	0	3,300	29,100	6,900	46,100	9%
1994 (part 90s)	1,700	0	2,500	15,500	16,250	35,950	7%
1997 (part 90s)	45,800	12,800	2,500	6,900	16,250	84,250	17%
Total yield	**280,000**	**18,500**	**33,100**	**91,500**	**85,300**	**508,400**	**100%**
Pct. of total	55%	4%	6%	18%	17%	100%	

1 In general, covers sediment delivery occurring from about the mid to late 1940s through 1998. Excludes surface erosion., which is estimated to represent less than 10% (and perhaps less than 5%) of total sediment delivery.
2 Landslides are recorded by photo year; as is the scour of channel fill deposits. All other sediment delivery is logged by decade of first occurrence. Decades are 1950s, 1960s, 1970s, 1980s and 1990s.
3 Includes all landslides identified in the air photo analysis, except those that were included in the road erosion inventory.
4 Bank erosion was assigned to the time when erosion appears to have first commenced. Some sites appear to erode over many years. Bank erosion for the 1990s was evenly divided between the 1994 and 1997 photo years.
5 The temporal distribution of scour in mechanically filled stream channels was not possible to determine in the field. Hence, erosion was considered initiated in the decade year in which the filling (tractor yarding) took place, and volumes (yields) were then divided between that and each of the following time periods according to the number of years in each photo period. The scour and channeling of these stored sediments appears to be a continuing process.
6 Yield from the 1990s was divided evenly between the two photo periods. One period was longer 1990-1994 but the other experienced a moderate storm 1995-1998.

delivery is the duration of time between major storm events. The longer the time interval, the lower the rate, all else remaining equal. Ideally, annual photographic coverage would allow for a more definitive determination of sediment production and delivery. It would allow for a much better definition of the true effects of each storm event on erosion and sedimentation in the watershed.

Table 10. Estimated sediment delivery rates for six times periods, North Fork Elk River watershed (P-L)				
Photo period	Watershed condition	Duration (yrs)	Sediment delivery (yds³)	Delivery rate[1] (t/mi²/yr)
Pre-1954	Estimated 7,100 acres clearcut in 1920s, 1930s, and 1940s using rail and cable; 2,800 acres tractor logged 1945-1954; 28 miles of logging road built	20 (Estimated)	98,500	320
1954-1966	1,050 acres tractor logged; clearcutting and channel filling; 22 miles of new logging road	12	179,200	980
1966-1974	2,155 acres tractor logged; clearcutting and channel filling; 25 miles of new logging road	8	64,400	530
1974-1987	Forest Practice Rules in effect; channel filling ends; 932 acres logged (4% cable); 9 miles of new logging road	13	46,100	230
1987-1994	2,419 acres logged (24% cable); 22 miles of new logging road	7	35,950	340
1994-1997	2,616 acres logged (88% cable); 26 miles of new, largely ridge road construction	3	84,250	1,840
Overall	Entire basin harvested with some second reentry in north; 133 miles of road constructed (P-L)	60+	508,400	550

[1] Assumes a bulk density of 100 lbs/ft³. Delivery rates are highly dependent on the duration of the time interval between photo years.

In practice, the shortest time interval available for the North Fork is for the three year period from 1994 to 1997. The calculated unit sediment delivery rate for the three year period from 1994-1997, based on our field data and aerial photo analysis, is just over 1,800 t/mi²/yr (84,250 yds³ over the three year period - see Table 10). Although this yield value is over an order of magnitude lower than the sediment delivery rate for the same three year period in Bear Creek (21,200 t/mi²/yr), it is still roughly twice as high as the 1966 period (which contained the 1955 and 1964 storms) in the North Fork Elk River. The relatively long record of the 1954-1966 period (12 years) serves to dilute the effects of the 1955 and 1964 storms and understates the importance of these events in the short term record.

Stream channel impacts following the 1997 flood in the North Fork Elk River were localized and not nearly as widespread or continuous as they were in Bear Creek. Only two photo periods (1966 and 1997) exhibited visually significant riparian canopy openings along the main stem as a result of sedimentation or channel migration in low gradient reaches of the lower watershed. Additional thalweg aggradation is likely to have occurred, but not to the extent that large areas of riparian canopy cover were affected in those areas.

Implementation Plan for Erosion Prevention and Control

A variety of erosion prevention and erosion control measures can be used to limit management-related sediment production and delivery in the North Fork Elk River watershed. These include measures to control and prevent both road-related and harvest-related sediment sources. Some measures, especially those along the road systems, are proactive projects designed to prevent future erosion. Most harvest-related mitigation measures are employed to avoid or modify land use activities on sensitive terrain.

Roads - Future road-related erosion

A total of 133 miles of P-L road were inventoried in North Fork Elk River to identify potential (future) sediment sources. Four mechanisms of road-related sediment production were identified: 1) those related to stream crossings (fluvial processes of crossing failure and stream diversion), 2) those related to mass wasting (usually road and landing fillslopes), 3) hillslope gullies below ditch relief culverts, and 4) persistent sediment sources (ditch and road runoff) (Table 11).

Stream crossings

A total of 335 stream crossings were inventoried (2.5 crossings/mile) in the North Fork. Most newly constructed roads (those built in the mid and late 1990s) have been built on upper hillslope areas and along ridge-tops, so these routes have very few streams or crossings. The 335 identified crossings include 120 culverted fills, 73 Humboldt log crossings, 24 culverted Humboldts, 8 bridges, 2 fords, 34 pulled crossings, and 71 unculverted fills. The 71 unculverted fills are located on very small streams so the erosion at most of these sites has been minimal. Flow at these crossings is generally diverted down the ditch to the nearest stream or ditch relief culvert. Several roads built within the last five years have been closed by excavating the stream crossing fills, as well as the potentially unstable road and landing fillslope materials. Treatment of stream crossings could prevent the delivery of over 180,000 yds^3 of sediment to the watershed's stream channels.

Serious erosion at stream crossings is often a result of flood flows exceeding the culvert capacity, culvert plugging, and/or stream diversion. Of the 120 culverted stream crossings in Elk River, 26 were diagnosed as having a high or moderate potential for culvert plugging, and 81 have been recommended for replacement because they are currently undersized for the 50-year flow. Of the 335 stream crossings in the watershed, 185 exhibit a potential for stream diversion (the road slopes away from the crossing). If the culvert or other drainage structure were to plug at these sites, streamflow would be diverted down the road. In the past, 58 separate stream diversions were documented to have occurred along the road system, and 51 streams are currently diverted. These diversions have produced a total of 5,076 yds^3 of erosion (Table 11).

Table 11. Sites of future erosion and sediment delivery along 133 miles of roads, North Fork Elk River watershed.

Sediment source	Number of sites with future delivery	Number of sites (or road miles) recommended for treatment	Estimated future sediment delivery (if not treated) (yds^3)
Stream crossings	331[1]	308	181,645[2]
Mass wasting (fills)	180	139	43,787
Ditch relief culverts	63	52	2,019
Other	87	42	1,205
Total	**661**	**541**	**228,656**
Persistent surface erosion[3]	18.7 miles	18 miles	unknown

[1] A total of 335 stream crossings were inventoried, with 4 having no expected future delivery.
[2] At stream crossings with a diversion potential, future gully erosion is difficult to predict. A minimum estimate of the stream crossing volume was used as a predicted value for this table.. This value is probably low, perhaps by a factor of 10.
[3] 18.7 miles of road ditch currently drain directly into stream crossing culverts.

Mass wasting (road-related)

Potential road-related mass movement features identified during the road inventory were divided into cutbank failures, landing fill failures, road fill failures and others. Of the 141 identified sites of correctable future road-related mass wasting identified along the road system, 107 are road fills, 26 are potential landing failures, 4 are cutbank instabilities, and 4 are other types of sites. Most of the potential road fill failures occur where the road crosses steep inner gorge slopes on the approach to a crossing of a deeply incised stream channel. The expected future delivery of landing failures, if they are not treated, would be 5,270 yds^3. Left untreated, road fill failures are expected to deliver over 18,000 yds^3 to the stream system.

Sediment delivery from potential road-related mass wasting sites was estimated to range from 10% to nearly 100%, depending on several site variables. In general, those with a higher delivery rate are located closer to a stream and on steeper slopes than those with less delivery. The average natural hillslope gradient for the 141 sites exceed 60%, but the distance to the receiving stream ranges from 0 feet (for those unstable fills which already toe out in the channel) to 500 feet for several potential landing fill failures. The average distance of potential fill failures with a high potential for future delivery is 70 feet from the nearest stream. Unstable fill slopes that are located 200-350 feet from the nearest stream channel were typically assigned a delivery of only 10% to 20%, at best. The few instabilities with a projected 100% delivery were located right next to the stream channel.

Erosion prevention

A total of 661 sites of potential future road-related erosion were inventoried in the North Fork Elk River watershed. All ditch relief culverts were mapped on the aerial photo overlays, but only those which could deliver sediment to a stream were included in the database of problem sites. All inventoried sites, by definition, showed future potential for sediment delivery to the North Fork or its tributaries. Some had already delivered sediment. A total of 543 sites have been recommended for treatment (Map 5). These include those sites most likely to yield sediment to stream channels in the future if erosion prevention work is not completed, and they are at locations where cost-effective work can be accomplished.

Treatment immediacy

Not all sites that display potential for sediment delivery to stream channels have the same need, or urgency (priority), for treatment. This fact led to the utilization of criteria for prioritizing all the potential work sites in Elk River. Recognition of site differences, and differences in erosion and sediment delivery potential, led to the development of a rating system based on ***"treatment immediacy."*** In the field, erosion features that threatened to deliver sediment to stream channels were designated as having a ***high, moderate or low "immediacy" of needed treatment.*** For all inventoried sites recommended for treatment, the Treatment immediacy is indicated on the inventory data sheet.

Site priority - Table 12 outlines the treatment immediacy (ie., priority) for 543 road-related erosion sites recommended for treatment in the watershed. Altogether, 141 sites were listed as having a high or moderate high need for treatment with a potential sediment "savings" of nearly 80,000 yds^3. Three hundred thirty (330) moderate and moderate/low priority sites account for an additional 133,860 yds^3 (Table 12). Finally, 72 sites are listed as having a low treatment immediacy with a potential sediment delivery of just over 14,800 yds^3.

Road priority - An efficient way of addressing treatment priorities is to identify high priority roads for treatment. This manner of treating sites maximizes equipment efficiency and minimizes the need to "jump around" the watershed treating only the high priority sites. Prioritizing roads is the preferred method of establishing watershed work plans for erosion prevention, and there are several way of developing a prioritized list.

Table 13 outlines the proposed work according to treatment immediacy by road in the North Fork Elk River watershed. Only the most "site-rich" roads have been listed. Those roads with the greatest number of sites are listed first. Another way of prioritizing is to list the roads in order of "number-of-sites/mile" or, alternatively, "volume saved/mile." Short roads with numerous sites having a high future yield then come to the top of the list. For example, the N75.35 road, at 1.29 miles long, would generate a potential sediment savings of over 10,500 yds^3/mile while longer roads (like the U road

Table 12. Treatment priorities for all inventoried sediment sources in the North Fork Elk River watershed.

"Immediacy" or Priority	Number	Future sediment delivery (yds^3)
High	41	31,150
Moderate/High	100	48,830
Moderate	205	94,730
Moderate/Low	125	39,140
Low	72	14,820
Total	**543**	**228,670 yds^3**

at 4.3 miles) would have a lower return of 2,800 yds^3/mile sediment savings even though they contain a large number of potential work sites. Roads like the N road and N-75 road are relatively long routes with a high potential return in sediment savings (about 7,000 yds^3/mi). They make good candidates for beginning a road-related erosion prevention program.

Reducing road-related sediment risks

A variety of treatments can be applied to prevent erosion and sediment yield to stream channels from roads and other eroding areas along roads in the North Fork Elk River. These include upgrading and erosion-proofing existing roads and landings, total or partial road decommissioning, and specific erosion control treatments along road surfaces, ditches, eroding stream banks, gullies and other bare soil areas. Sites which are expected to erode and deliver sediment to streams in the future are the only locations where opportunity exists for meaningful erosion control and erosion prevention work. At these locations, a variety of specific treatments can be employed to control and prevent future erosion and sediment delivery to stream channels.

Types of prescribed heavy equipment erosion prevention treatments

Generic specifications for a variety of preventive watershed treatments have been developed for decommissioning and erosion-proofing (upgrading) roads and landings. Recommended treatments may range from no treatment or simple cross-road drain construction, to full road decommissioning (closure), including the excavation of unstable sidecast materials, road fills, and all stream crossing fills. A number of roads in the North Fork can be targets for decommissioning or temporary closure.

Road upgrading involves a variety of treatments used to make a road more resilient to large storms and flood flows. The most important of these include stream crossing upgrading (especially culvert up-sizing, to accommodate the 50-year storm flow and debris in transport, and to eliminate stream diversion potential), removal of unstable sidecast and fill materials from steep slopes, and the application of drainage techniques to improve dispersion of road surface runoff. The road drainage techniques include berm removal, road outsloping, rolling dip construction, and/or the installation of

Table 13. Top road treatment priorities based on site density and future delivery, North Fork Elk River watershed[1]					
Road	No. of sites to treat	High Immediacy	High/Moderate Immediacy	Moderate Immediacy	Volume "saved" (yds^3)
N75	37	8	8	21	17,150
U	27	2	7	18	12,120
N	26	6	5	15	16,280
N80	20	2	9	9	3,260
N75.35	17	1	5	11	13,600
N80.51	17	0	11	6	8,260
U46.19	17	2	7	8	6,710
U46	15	0	6	9	8,210
U46.12	14	2	1	11	7,970
N75.49	11	2	4	5	10,060
N75.09	9	0	2	7	2,990
N75.11	8	1	2	5	4,400
N80.35	8	1	2	5	1,370
U11	8	1	4	3	2,570
Total	**234**	**28**	**73**	**133**	**114,950 yds^3**

[1] All other roads and sites .... (307 sites and an additional 113,055 yds^3 on a number of roads)

ditch relief culverts. The goal of all treatments is to make the road as "hydrologically invisible" as is possible.

General heavy equipment treatments for *road decommissioning* or closure are newer and less well published, but the basic techniques have been tested, described and evaluated. Decommissioning essentially involves "reverse road construction," except that full topographic obliteration of the road bed is not normally required to accomplish sediment prevention goals. In order to protect the aquatic ecosystem, the goal is to "hydrologically" close the road; that is, to minimize the adverse effect of the road on natural hillslope processes and watershed hydrology. Several roads in Elk River, including portions of the N75 Road, and several of its spurs, have been recommended for permanent hydrologic closure.

Typically, potential problem areas along a road are isolated to a few locations (perhaps 10% to 20% of the road network to be decommissioned) where stream crossings need to be excavated, unstable landing and road sidecast needs to be removed before it fails, or roads cross potentially unstable terrain and the entire prism needs to be removed. Most of the remaining road surface simply needs permanently improved surface drainage, using decompaction, road drains and/or partial outsloping. Table 14 lists a number of treatments and their typical applications.

Table 14. Sample techniques and applications for temporary or permanent road closure

Treatment	Typical use or application
Ripping or decompaction	improve infiltration; decrease runoff; assist revegetation - used in decommissioning
Construction of rolling dips and cross-road drains	drain springs; drain insloped roads; drain landings. Installation of critical dips is key to road upgrading.
Partial outsloping (local spoil site; fill against the cutbank)	remove minor unstable fills; disperse cutbank seeps and runoff
Complete outsloping (local spoil site; fill against the cutbank)	used for removing unstable fill material where nearby cutbank is dry and stable - a decommissioning tool.
Exported outsloping (fill pushed away and stored down-road)	used for removing unstable road fills where cut banks have springs and cannot be buried
Landing excavations (with local spoil storage)	used to remove unstable material around landing perimeter - used in upgrading and decommissioning.
Stream crossing excavations (with local spoil storage)	a road decommissioning technique; complete removal of stream crossing fills (not just culvert removal)
Truck endhauling (dump truck)	hauling excavated spoil to stable, permanent storage location where it will not discharge to a stream

Control of persistent sources of sediment yield from roads, ditches and cutbanks

Road cutbanks and road ditches are thought to deliver relatively significant volumes of fine sediment to some watersheds (e.g.., Reid, 1981) and they have been found to significantly affect watershed hydrology (Wemple, 1994). In the North Fork Elk River, 18 miles of roadside ditch drain directly into stream crossing culverts. This may seem like a relatively unimportant sediment source relative to landslides and gullies, but persistent fine sediment production can impede the recovery of fish-bearing streams.

Relatively simple, inexpensive treatments can be performed to upgrade road drainage systems to significantly reduce or largely eliminate these watershed effects. Fine sediment can usually be prevented from entering culverted stream crossings by installing a series of rolling dips or ditch relief culverts just up-road from stream crossings, and/or by outsloping roads in the immediate vicinity of stream crossings to disperse road runoff.

Treatments

A computerized database of all the sites recommended for treatment has been developed in MS Access format compatible with Pacific Lumber Company's road database. Site numbers, site locations, descriptions, prescriptions, equipment requirements and potential sediment savings are outlined in detail in the database for each site (see Appendix A). The specific location of each site recommended for treatment is shown on Map 5. Inventory sites have been also been plotted on 1:12,000 mylar overlays to 1997 color aerial photos of the watershed. Each site is also flagged in the field.

Site specific treatments - Table 15 summarizes recommended erosion prevention and road upgrading treatments for roads in the North Fork Elk River watershed. The database, as well as the field inventory sheets, provide details of the treatment prescriptions for each site. Most treatments require the use of heavy equipment, including an excavator, tractor, dump truck and/or backhoe. Some hand labor is required at sites needing new culverts or culvert repairs.

Recommended treatments range from upgrading existing roads that are favorably located, to closing (decommissioning) roads which are no longer needed or are located in hillslope areas where high rates of erosion and sediment yield are occurring or can be expected. Most roads in the basin have been recommended for upgrading, but a number of abandoned roads and roads in riparian zones are also suggested for closure.

Many culverted stream crossings on designated permanent and seasonal roads were observed to be undersized for the design runoff event (50-year). Plugging or overtopping during high flow events in the past has caused numerous past stream diversions and episodes of stream crossing erosion. On roads recommended for upgrading, we have calculated drainage areas and performed discharge calculations for the 50-year storm runoff peak at stream crossings which appeared to have undersized culverts. The mathematical algorithm, based on the Rational formula for calculating peak flows from small watersheds, has been modified and incorporated into a spread sheet format. This numerical model was used to estimate peak discharges and appropriate culvert sizes. The recommended culvert sizes included in the treatment database shown on the data sheet for each stream crossing site is based on this model, modified as necessary to fit field conditions and observations. Field evidence and discharge calculations from at least 82 sites indicate that a culvert upgrade is warranted.

A common treatment prescribed for upgrading stream crossing sites is for the installation or construction of rolling dips to eliminate the potential for stream diversion. These are called "critical dips" in the treatment database (Table 15). Critical dip installation is a simple, inexpensive, preventive erosion control technique which provides protection to the road system (and downstream areas) during the most extreme winter floods, when culverts may become plugged or their capacity exceeded. In total, 126 critical dips have been recommended for installation at stream crossings on permanent and seasonal roads. The treatment takes a tractor about one hour (plus re-rocking, where necessary) to perform.

Table 15. Recommended treatments along roads in the North Fork Elk River watershed.

Treatment	No.	Comment	Treatment	No.	Comment
Critical dip	126	To prevent stream diversions	Remove berm	10	Remove 2,170 feet of road berm
Install cmp	61	Install a cmp at an unculverted fill	Outslope road	13	Outslope 3,335 feet of road to improve road surface drainage
Replace cmp	82	Upgrade an undersized cmp	Inslope road	3	Inslope 320 feet of road
Excavate soil	397	Typically fillslope & crossing excavations; excavate a total of 231,948 yds^3	Clean ditch	18	Clean 3,283 feet of ditch
Clean cmp	9	Clean a cmp inlet to prevent plugging	Install ditch relief cmp	18	Install ditch culverts; use rolling dips if possible
Trash racks	5	Installed to prevent culvert plugging	Install rolling dips	286	Install rolling dips to improve road drainage
Down spouts	36	Installed to protect the outlet fillslope from erosion	Remove ditch	2	Remove 990 feet of inboard ditch
Armor outboard fill face	2	Rock armor to protect the fill face from erosion	Other	54	Miscellaneous treatments
Rock road surface	1	Rock road surface using 1400 ft^2 of rock	No treatment recommended	153	
Wet crossing	1	Install a rocked rolling dip or armored fill			

Control of ditch and road surface fine sediment yield - There are several ways to effectively reduce the contribution of fine sediment from road ditches. First, road-side ditches near stream channels can be eliminated by outsloping the road bed and dispersing runoff rather than collecting and concentrating it in ditches. In this strategy, not all the road ditches in the watershed would have to be eliminated or shortened, just the ones that drain road and cutbank runoff directly into stream channels. Alternatively, a series of rolling dips or ditch relief culverts could be installed just up-road from each stream crossing so that ditch runoff (and eroded sediment) is diverted and dispersed on the hillslope below the road rather than being discharged through the ditch and into the inlet of the stream crossing culvert. Because installation of ditch relief culverts also increases long term maintenance requirements, rolling dips are the preferred method for road surface drainage.

Along upgraded roads, approximately 18 miles of ditch can be disconnected from the stream system by the installation of rolling dips and ditch relief culverts. Culverts or dips (which intercept all ditch flow) would need to be installed approximately 50-75 feet up-road of each crossing to achieve maximum effectiveness at reducing sediment contributions to the stream channel. Specific locations for the placement of rolling dips and ditch relief culverts should be mapped in the field just prior to equipment work so that sediment and water from ditches can be effectively dispersed onto hillslopes below the road with no threat that it will enter the stream channel, result in gullying or aggravate slope stability problems. Stream crossings requiring this treatment have been identified in the treatment database.

Equipment needs and costs

Treatments in the watershed will require over 5,600 hours of excavator time and 5,800 hours of tractor time to complete all prescribed upgrading, road closure, erosion control and erosion prevention work at the 543 recommended treatment sites (Table 16 and Map 5). Excavator and tractor work is not needed at all the sites that have been recommended for treatment and, likewise, not all the sites will require both a tractor and an excavator. Approximately 2,400 hours of dump truck time has been listed for work in the basin for endhauling excavated spoil from stream crossings and unstable road and landing fill where local disposal sites are not available.

Table 16. Heavy equipment requirements for road-related erosion prevention, Elk River watershed

Treatment Immediacy	No.	Future Yield (yds^3)	Excavator (hrs)	Tractor (hrs)	Dump Trucks (hrs)	Backhoe (hrs)	Labor (hrs)
High, High/Moderate	141	79,980	2,080	2,207	1,233	1	327
Moderate, Moderate/Low	329	133,870	3,371	3,442	1,096	1	530
Low	71	14,820	192	223	87	3	26
Total	**543**	**228,670**	**5,643**	**5,872**	**2,416**	**5**	**883**

Estimated costs for erosion prevention treatments - Prescribed treatments are divided into two components: a) site specific erosion prevention work identified during the watershed inventories, and b) control of persistent sources of road surface, ditch and cutbank erosion and associated sediment delivery to streams. The site-specific work is further divided into road upgrading activities and road closure activities. Total costs for the project are estimated at approximately $1,594,000, for an average cost-effectiveness value of approximately $7.00 per cubic yard of sediment prevented from entering Elk River and its tributaries.

Overall site specific erosion prevention work: Equipment needs for site specific erosion prevention work are expressed in the database, and summarized on Table 16, as direct excavation times, in hours, to treat all sites in the basin which have a high, moderate, or low treatment immediacy. These hourly estimates include only the time needed to treat each of the sites, and do not include travel time between work sites, the time needed to reconstruct or clear roads which have been abandoned, or the time needed for work conferences at each site. These additional times are accumulated as "logistics" and must be added to the work times to determine total equipment costs as shown in Table 17. Costs in Table 17 assume that the work in this watershed is accomplished during a two summer work periods employing one or two equipment teams. This minimizes moving and transport costs for equipment and personnel.

Elk River hillslopes - landslide prevention and avoidance

The second strategy for reducing management-related sediment production in the basin involves efforts needed to minimize the risk of accelerated landsliding. The sediment source inventory has shown that debris sliding is an important sediment production mechanism in the watershed. Landsliding on inner gorge slopes and inner gorge swales is the most common and obvious geomorphic association in the watershed, accounting for 65% of the hillslope landslides (by number) and 44% of the sediment delivery by all landslides. Large landslides (those exceeding 3,000 yds^3 in delivery volume) comprise 68% of the total measured landslide yield but only 11% of the total number of slides (Table 4). Seventeen of the 23 large and very large landslides identified in the North Fork Elk River watershed occurred prior to 1966.

Because landslides, especially large landslides, have been volumetrically important contributors to historic sediment delivery to the stream system, it would be useful if their point of initiation could be identified and managed for reduced risk. Such management can take two basic forms: 1) generic identification of potentially susceptible sites, followed by exclusion, limitation and/or modification of operations in all the areas which match these sites, or 2) site specific identification and analysis of potentially susceptible sites at each proposed area of land use activity, and the prescription and implementation of unique limitations and/or restrictions on proposed activities at those locations.

Unfortunately, there is little indication from the preliminary aerial photo analysis that large and very large landslides occur in unique settings (relative to geology, geomorphology, harvesting, and roading) in the North Fork Elk River watershed, as compared to smaller, more common landslides,

Table 17. Estimated logistic requirements and costs for road-related erosion control and erosion prevention work along 133 miles of roads, N. Fk. Elk River watershed

Cost Category[1]		Cost Rate[2] ($/hr)	Estimated Project Times			Total Estim. Costs[5] ($)
			Treatment[3] (hours)	Logistics[4] (hours)	Total (hours)	
Move-in; move-out[6] (Low Boy expenses)		70	64	--	64	4,480
Heavy Equipment	D-7 size tractor	80	5,872	1,762	7,634	610,720
	Excavator	100	5,643	1,693	7,336	733,600
	Backhoe	65	5	2	7	455
	Dump Truck	55	2,416	725	3,141	172,755
Laborers		20	883	265	1,148	22,960
Layout, Coordination, Supervision, and Reporting[7]		35	---	--	1389	48,615
Total Estimated Costs						**$1,593,585**

[1] Costs for tools, new culvert materials, for mulching and related materials (grass seed, fertilizer and straw), and for plant materials have not been included in this table. Culvert costs could be considerable. Costs for administration and contracting are variable and have not been included. Costs and dump truck time (if needed) for re-rocking the road surface at sites where upgraded roads are outsloped, where rolling dips are constructed and where stream crossing culverts are replaced or upgraded have not been estimated.

[2] Costs listed for heavy equipment include operator and fuel. Costs listed are estimates for favorable local private sector equipment rental and labor rates.

[3] Treatment times include all equipment hours expended on excavations and work directly associated with erosion prevention and erosion control at all the sites.

[4] Logistic times for heavy equipment (30%) include all equipment hours expended for opening access to sites on maintained and abandoned roads, travel time for equipment to move from site-to-site, and conference times with equipment operators at each site to convey treatment prescriptions and strategies. Logistic times for laborers (30%) includes estimated daily travel time to project area.

[5] Total estimated project costs listed are averages based on private sector equipment rental and labor rates.

[6] Lowboy hauling for tractor and excavator, four hours round trip each piece. Costs assume 2 hauls for two pieces of equipment to each side of the Elk River watershed (one to move in and one to move out) for 2 years.

[7] Supervision time includes detailed layout (flagging, etc) prior to equipment arrival, training of equipment operators, supervision during equipment operations, supervision of labor work and post-project documentation and reporting). Supervision hours based on one quarter of the excavator time.

or that a blanket management strategy of avoidance of large areas of the landscape would be a reasonably productive strategy compared to site specific analysis. For example, most inner gorge slopes and steep inner gorge swales in the watershed have not produced historic landslides, especially large landslides, even though it can be assumed that they have an increased susceptibility compared to gentler, more planar terrain. Instead, it might be more fruitful to conduct more detailed analysis of the sites of recent landslides to determine if there are unique physical characteristics that could be recognized in the field to better define the overall character and distribution of the failure sites across the landscape that may not be evident on aerial photos. This field information may also be useful to improve the predictive capability of geological field reviews of potential harvest areas so as to better identify potential initiation sites.

To mitigate or reduce the influence of management on overall slope stability in the North Fork Elk River watershed, steps should be undertaken to better characterize and predict potential slope stability problems before land management is undertaken. The best mechanism to accomplish this is still the use of trained and competent geologists to conduct field inspections and perform geomorphic site analysis for all harvesting and road construction plans in sensitive portions of the landscape. The most important sites to identify and inspect include inner gorge slopes (>65%), streamside slopes (<65%) and steep headwall swales. Inspection, analysis, avoidance, vegetation retention and other measures to accomplish should be employed. Appropriate measures to accomplish this are included in PALCO's "Interim Aquatic Strategy for Timber Harvest and Roads", including the attached document "Mass Wasting Avoidance Strategy for the Interim Period." Sites should be identified, and measures should be prescribed by the field geologist, based on site conditions (slope gradient, hillslope position, slope shape, hydrology, geomorphic feature, etc).

North Fork Elk River Monitoring Plan

A variety of techniques are available to document the physical and biological changes which take place in the stream system of the North Fork Elk River. The most useful strategy will be one that documents changes in aquatic habitat condition and utilization, as well as physical changes in channel morphology in the main stem. Pacific Lumber Company already has monitoring stations in Elk River and the Company plans to continue to collect data at these sites. PALCO will augment the existing monitoring with several measures to document physical channel changes in the future. Once monitoring stations have been permanently established, sites will be remeasured only as conditions warrant. This may be annually for the first several years and then every two to five years, or as storms and floods dictate.

Physical channel monitoring will include two main elements:

1. Photo points - Permanent photo point stations will be established along the main channel to document the deposition and scour sediment in the main stem. A select number of photo point stations will be permanently established for repeated photography to document channel changes.

2. Cross section measurements - A number of permanently monumented channel cross sections will be established along the length of the lower main stem of the North Fork Elk River to document rates of channel scour, deposition and channel migration. Reaches which are sensitive to change (especially aggradation) will be identified and measured. The cross section sites will be identified and installed this summer when stream levels have dropped.

The combined physical and biological monitoring program will provide a evolving, long term picture of physical and biological processes in the lower main stem of the North Fork Elk River. The precise location of monitoring stations will be established this summer, and PALCO will permanently identify the type of monitoring and the measurement techniques for each site at that time. The monitoring stations will be incorporated in the Company's GIS mapping program.

Summary and Conclusion

A variety of processes are responsible for sediment production and yield in the Elk River watershed. These include mass wasting (mostly debris sliding), minor debris torrenting (including limited torrent track scouring), scouring of mechanically "filled" low order stream channels, stream bank erosion, and surface erosion. Road-related erosion consisted of mass wasting processes (cut bank, road fill and landing fill), fluvial processes (steam crossings washouts, stream diversion gullies, gullies from ditch relief culverts) and road-related surface erosion).

Mass wasting is the most important sediment production process measured in the North Fork Elk River watershed. Both numerically and volumetrically, the most important sediment production mechanism in the historical post-management (post-1940s) period has been debris landsliding from steep inner gorge (>65%) and streamside (<65%) slopes. Nearly 65% of the 204 landslides in the watershed occurred on inner gorge slopes, and they delivered 44% of the landslide volume that is estimated to have reached streams (Table 3). Steep stream side slopes (<65% steepness) accounted for another 16% of all landslides. Roughly 55% of sediment production from all sources, over all photo years (combined), originated from debris landslides (Table 9). Significantly, eighty percent of the measured landslide volume delivered to streams since the 1940's occurred prior to 1974. Sixteen percent, triggered by three historically large storms, occurred in the period from 1994 to 1997 (Table 9).

Large landslides are an important component of the long term historical sediment budget. The largest debris slides (those >3,000 yds^3) accounted for only 11% of the number of landslides inventoried, but 68% of total landslide sediment yield (Table 4). Unfortunately, there is little indication from the aerial photo analysis that large and very large landslides occur in unique settings in the North Fork Elk River watershed, as compared to smaller, more common landslides, or that uniquely managing for them would be technically feasible or productive. They occur on both streamside (50-65%) and inner gorge (>65%) slopes, and they are associated with all management practices (roads, partial cuts, clear cuts and advanced second growth) and ages of harvest (<15 years and >15 years). They develop on slopes from 40% to 75% in steepness, with an average initiation gradient of between 50 and 60 percent. Such slopes (>50%) are very common in the watershed, covering over 40% of the landscape of the North Fork.

Both road construction and harvesting have been linked to increased sediment production and yield in the North Fork Elk River. Harvesting began in the watershed in the 1880s, and has probably been associated with increased rates of mass wasting, although the degree of increase attributable to land use is not clear. It is an expected relationship. Regardless of the management associations, it is clear that most landslides from all time periods occurred on steep inner gorge and streamside slopes, and that the largest storms (including those of the late 1990s) have triggered, or been associated with, the greatest increases in landslide rates in the watershed.

Watershed sediment production for the period of record has been apportioned among five general sediment production mechanisms: debris landslides (55%), torrent track scour (4%), bank erosion (6%), scour of mechanically filled, low order stream channels (18%) and road-related erosion (17%) (Table 9). Because failed stream crossings are reconstructed along all maintained roads, thereby concealing past erosion and sediment delivery, we believe past road-related sediment delivery from this process may be underestimated by as much os 50%. Management-related sediment production from surface erosion was not measured for this study but is estimated to account for less than 10% (and perhaps less than 5% due to rapid revegetation) of total watershed sediment delivery[4].

Sediment delivery rates (Table 10) suggest that watershed sediment production and delivery to the stream system fluctuates, and has been influenced by both the intensity and nature of harvesting, road location and construction practices, as well as the frequency, magnitude and intensity of major storms. Delivery rates are also influenced by the time period over which averages are calculated (the shorter the period, the higher the rate, all else being equal). Relatively high rates of sediment delivery measured from the 1997 photography (triggered by three large storm events in 1996 and 1997) was preceded by much lower rates during the relatively long storm-free period from 1974 to 1994.

An implementation plan has been prepared for erosion control and erosion prevention along 133 miles of road in the North Fork Elk River watershed. Roads have been prioritized for upgrading and closure, depending on their location, current status and physical condition. A database of treatment prescriptions, equipment and labor requirements and estimated costs has been prepared for each of the 543 sites recommended for treatment. Implementation of the work plan will prevent the future delivery of over 228,000 yd^3 of sediment to the North Fork Elk River and its tributaries at an estimated cost of approximately $1,594,000.

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[4] Surface erosion rates for road surfaces and bare soil areas over the period from 1954 to 1980 have been estimated for the nearby 280 mi^2 Redwood Creek watershed (Madej, written communication). There they are estimated to account for between 10% and 12% of total basin sediment delivery.

A landslide prevention and avoidance strategy has also been proposed. It is based on minimizing the effects of forest management activities on potentially unstable inner gorge slopes where debris landsliding is a common and important sediment production process. It is based on field recognition and the application of avoidance or modified land management practices. The strategy includes a number of measures generally described in the newly developed "Interim Aquatic Strategy for Timber Harvest and Roads" and the associated procedures described in "Mass Wasting Avoidance Strategy for the Interim Period" (see Appendix B). Additional, specific measures will be developed for each proposed site based on the nature of site conditions and on-the-ground field analysis of geomorphic sensitivity.

Finally, a monitoring plan has been proposed to document and track physical and biological changes which take place in the lower main stem of the North Fork Elk River. The existing monitoring stations will be supplemented with the establishment of a number of long term physical monitoring stations. Physical monitoring will involve repeated ground-level stereo photographic documentation of channel conditions from monumented photo-point stations, and profile and cross section surveys to determine the location, nature and rate of future channel changes and sediment flushing (or aggradation).

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Sediment Source Investigation and Sediment Reduction Plan for the Elk River Watershed, Humboldt County, California

APPENDICES

Appendices ***Page***

Appendix A

PWA ROAD INVENTORY DATA FORM (3/98 version)

Check ____

[illegible]	Site No: ____	GPS:	Watershed:		CALWAA:		
[illegible] N):	Photo: ____	T/R/S:	Road #:		Mileage: ____		
	Inspectors: ____	Date: ____	Year built: ____	Sketch (Y):			
	Maintained	Abandoned	Driveable	Upgrade	Decommission	Maintenance	
[illegible] M	Stream xing	Landslide (fill, cut, hill)	Roadbed (bed, ditch, cut)	DR-CMP	Gully	Other	
	Location of problem (U, M, L, S)	Road related? (Y)	Harvest history: (1=<15 yrs old; 2=>15 yrs old) TC1, TC2, CC1, CC2, PT1, PT2, ASG, No		Geomorphic association: Streamside, I.G., Stream Channel, Swale, Headwall, B.I.S.		
[illegible]LIDE	Road fill	Landing fill	Deep-seated	Cutbank		Already failed	Pot. failure
	Slope shape: (convergent, divergent, planar, hummocky)			Slope (%) ____	Distance to stream (ft) ____		
[illegible]	CMP	Bridge	Humboldt	Fill	Ford	Armored fill	
	Pulled xing: (Y)	% pulled ____	Left ditch length (ft) ____		Right ditch length (ft) ____		
	cmp dia (in) ____	inlet (O, C, P, R)	outlet (O, C, P, R)	bottom (O, C, P, R)	Separated?		
	Headwall (in) ____	CMP slope (%) ____	Stream class (1, 2, 3)	Rustline (in)			
	% washed out ____	D.P.? (Y)	Currently dvted? (Y)	Past dvted? (Y)	Rd grade (%) ____		
	Plug pot: (H, M, L)	Ch grade (%) ____	Ch width (ft) ____	Ch depth (ft) ____			
	Sed trans (H, M, L)	Drainage area (mi²) ____					
[illegible]ION	E.P. (H, M, L)	Potential for extreme erosion? (Y, N)		Volume of extreme erosion (yds³): 100-500, 500-1000, 1K-2K, >2K			
[illegible]	Rd&ditch vol (yds³) (yds³) ____	Gully fillslope/hillslope (yds³) ____	Fill failure volume (yds³) ____	Cutbank erosion (yds³) ____	Hillslope slide vol. (yds³) ____	Stream bank erosion (yds³) ____	xing failure vol (yds³) ____
	Total past erosion (yds) ____	Past delivery (%) ____	Total past yield (yds) ____	Age of past erosion (decade) ____			
[illegible]ion...	Total future erosion (yds) ____	Future delivery (%) ____	Total future yield (yds) ____	Future width (ft) ____	Future depth (ft) ____	Future length (ft) ____	
[illegible]NT	Immed (H,M,L)	Complex (H,M,L)	Mulch (ft²)				
	Excavate soil	Critical dip	Wet crossing (ford or armored fill) (circle)		sill hgt (ft) ____	sill width (ft) ____	
	Trash Rack	Downspout	D.S. length (ft) ____	Repair CMP	Clean CMP		
	Install culvert	Replace culvert	CMP diameter (in) ____	CMP length (ft) ____			
	Reconstruct fill	Armor fill face (up, dn)	Armor area (ft²) ____	*Clean or cut ditch*	*Ditch length (ft)* ____		
	Outslope road (Y)	*OS and Retain ditch (Y)*	*O.S. (ft)* ____	*Inslope road*	*I.S. (ft)* ____	*Rolling dip*	*R.D. (#)* ____
	Remove berm	*Remove berm (ft)* ____	*Remove ditch*	*Remove ditch (ft)* ____		*Rock road - ft²* ____	
	Install DR-CMP	*DR-CMP (#)* ____	Check CMP size? (Y)	Other tmt? (Y)	No tmt. (Y)		

[illegible]ENT ON PROBLEM:

[illegible]ATION VOLUME	Total excavated (yds³) ____	Vol put back in (yds³) ____	Volume removed (yds³) ____	
	Vol stockpiled (yds³) ____	Vol endhauled (yds³) ____	Dist endhauled (ft) ____	Excav prod rate (yds³/hr) ____
[illegible]MENT HOURS	Excavator (hrs) ____	Dozer (hrs) ____	Dump truck (hrs) ____	Grader (hrs) ____

	Loader (hrs) ______	Backhoe (hrs) ______	Labor (hrs) ______	Other (hrs) ______

COMMENT ON TREATMENT:

Stream Profile Through Crossing

(begin at top of profile)

Xing type 1, 2, 3, 4 (Circle)

Angle (deg) (dwn=-)	Distance (feet)	Code (UES, TOP, IBR, OBR, BOT XS1, XS2...LES)	Comment
0	0	UES, TRN	in natural channel

Cross Section(s) (begin on left bank)

xs#	Angle (deg)	Distance (feet)	Code (LRP, LEC, CLP, REC, RRP)	Comment
1	0	0	LRP, TRN	Base of cutbank

Computer volumes- 1. Computer erosion volume (1:1): ______

3. Humboldt excavation volume (1:1): ______

2. Culvert excavation vol (add/repl - 1:1): ______

4. Decommission volume (2:1): ______

Site Sketch - Site No.______

Appendix B

DRAFT INTERIM AQUATIC STRATEGY
(March 1998 thru ~March 2002)
FOR TIMBER HARVEST & ROADS
FOR THE PACIFIC LUMBER CO. HCP

Management Zone	Prescription	Related Function/Indicator
Channel Migration Zone (CMZ) - needs more discussion, CDFG geologist is providing some information All segments of Class I and Class II streams that have a Rosgen type C , D, or E channel morphology will be examined to identify the bankfull channel and the remaining portion of the floodplain that is likely to become part of the active channel during the 50 years covered by the ITP as evidenced by past channel migration and other field indicators. CMZ evaluations will be conducted as part of the Watershed Analyses that are planned for each basin on the ownership. Areas not evaluated in a watershed analysis must be analyzed separately by PL using a qualified fluvial geomorphologist who has expertise in channel migration before any THP abutting such areas can be approved. PL will consult[1] with NMFS, CDF&G, USFWS, and EPA or Water Quality regarding any such mapping - it is assumed all other areas are equivalent to the >97 CFPR permanent vegetation transition zone. * Willows are not to be considered permanent vegetation.	- Management to enhance and facilitate riparian functions, [only] may be allowed based upon a completed Watershed Analysis and Riparian Management Plan as agreed upon (both processes) by the permiting agencies. - no sanitation salvage or exemption harvest (including emergency harvest exemptions), unless ... * loss of life or property [loss of property is defined as a demonstrated high risk of loss of capitol improvements (bridges, roads, culverts, houses, not including vegetation)]; * or other emergencies as per agreement with NMFS, FWS and CDF&G in accordance with approved HCP - no forest chemical use (herbicides, pesticides, and fertilizers)	Bank Stability, LWD protection, Off-channel habitat protection, Channel migration protection, microclimate protection, pools, etc.

[1] Consult as used here includes the following: prior to submission of any THP affected by CMZs PL shall include copies of the proposed THP, including the THP number, a map of the area proposed for harvest, silviculture prescription, and a copy of the geomorphologist's report. PalCo shall seek approval, acceptance, or notice of "no response" from NMFS, FWS, CDF&G, and EPA or Water Quality. If the notified agencies have concerns regarding the harvest proposal, they shall communicate such concerns to the RPF and CDF within 30 days of receipt of materials from PL or until the close of the public comment period, whichever is longer. Results of the consultation must accompany the THP when submitted for review.

2) Limited Entry Band 30' to 100' - prescriptions apply to each side of the watercourse * indicates prescriptions that apply to the entire 0-170' width (i.e. Band #1 and #2) -	PalCo=s Late Seral, High Residual Prescription - single tree selection - minimum 345 sq ft preharvest conifer basal area per acre of Band #2 RMZ, each side - minimum 300 sq ft post harvest conifer basal area per acre of Band #2 RMZ, each side - basal area measurements will be made for conformance no less than every 200' lineal segment of RMZ as per the CFPR=s 916.4(b)(2) - no more than 40% of the conifer basal area may be harvested in a single entry - tree sizes and quantity distribution retained as per HCP Appendix 14 (Aug 25, >97) [if replacement size classes must be used to obtain the stated size distributions, the replacement size class must come form the next higher class] - maximum 1 entry per 20 years - No sanitation salvage or exemption (including emergency exemptions) harvest (as defined in >97 CFPR=s) except for emergencies as per agreement with NMFS, FWS, and CDF&G. in accordance with the approved HCP - EEZ for timber operations except for permitted equipment crossings as agreed upon by NMFS, CDF&G, and USFWS, and roads. - watershed analysis and/or PWA protocol will be used to determine the priorities and road armoring standards to be used on all roads inside Band #2 (limited entry band) Surface area covered in roads will be included in all calculations of basal area. - full suspension yarding only; conditions (not locations) where full suspension is not possible will be identified in the HCP. For these conditions, yarding will be conducted in a manner that avoids ground disturbance that may deliver sediment to a watercourse to the maximum extent practicable. Where ground disturbance occurs PL will treat (e.g., through seeding, mulching, etc.) all sites with exposed mineral soil that can reasonably be expected to deliver sediment to a watercourse (e.g. gullies, ruts). Trees damaged in the cable yarding corridors must be retained in place. -	Bank Stability, LWD protection and recruitment, temperature, sediment filtration, microclimate, soil compaction

	- 10 trees per acre on each side of the watercourse are to be retained greater than 40" dbh, permanently marked [can be counted entirely or partially in Band#1] * retain ALL portions of down wood (i.e. LWD/LOD) except as defined as slash in the Z=Berg-Nejedly Forest Practice Act Article 2, 4525.7 * trees felled during current harvesting and approved THP roads construction are not considered down wood for purposes of retention. * felled hazard trees or snags not associated with a THP are considered down wood and are to be retained in the general vicinity * trees that fall naturally onto a roads, landings, harvest units are considered down wood and are to be retained in the general vicinity * no forest chemical use (herbicides, pesticides, and fertilizers) * retain <u>all</u> non-hazard snags, as per the snag policy in the HCP		

	3) Outer Band 100' to 170' - prescriptions apply to each side of the watercourse	-PalCo's late seral prescription - single tree selection - minimum 276 sq ft pre harvest conifer basal area, per acre of RMZ, each side - minimum 240 sq. ft post harvest conifer basal area, per acre of RMZ, each side - no more than 40% of the conifer basal area may be harvested in a single entry - tree sizes and quantity retained as per Appendix 14 in the HCP (Aug 25 '97) [if replacement size classes must be used to obtain the stated size distributions, the replacement size class must come form the next higher class] - basal area measurements will be made for conformance no less than every 200' lineal segment of RMZ as per the CFPR's 916.4(b)(2) - No sanitation salvage or exemption (including emergency exemptions) harvest (as defined in '97 CFPR's) except for emergencies as per agreement with NMFS, FWS and CDF&G. in accordance with the approved HCP - EEZ for timber operations except for permitted equipment crossings as agreed upon by NMFS, CDF&G, and USFWS, and roads. - <u>for slopes <50% portions of downed wood</u> (ie. LWD/LOD) can be removed from Band #3 [if a tree originating in any of the 3 Bands falls, portions in Bands #1 & 2 must be retained onsite in place, but the portions in Band #3 can be removed for slopes <50%.] - <u>for slopes 50% or greater, all down wood</u> (ie. LWD/LOD) must be retained except as defined as slash in the Z'Berg-Nejedly Forest Practice Act Article 2, 4525.7 in the '97 CFPR, page 207 - full suspension yarding only; conditions (not locations) where full suspension is not possible will be identified in the HCP. For these conditions, yarding will be conducted in a manner that avoids ground disturbance that may deliver sediment to a watercourse to the maximum extent practicable. Where ground disturbance occurs PL will treat (e.g., through seeding, mulching, etc.) all sites with exposed mineral soil that can reasonably be expected to deliver sediment to a watercourse (e.g. gullies, ruts). Trees damaged in the cable yarding corridors must be retained in place.	LWD recruitment, temperature, sediment filtration, soil compaction, microclimate, windthrow

CLASS II Riparian Management Zone 100' total width * measured slope distance	1) Restricted Harvest Band Edge of CMZ 0-10'	- Management to enhance and facilitate riparian functions, [only] may be allowed based upon a completed watershed analysis and riparian management plan as agreed upon (both processes) by the permitting agencies - if the 10' line falls anywhere on a tree bole, then the tree is to be retained as part of the Restricted Harvest Band - - No sanitation salvage or exemption (including emergency exemptions) harvest (as defined and allowed in the >97 CFPR=s) except for emergencies as per agreement with NMFS, FWS and CDF&G in accordance with the approved HCP - EEZ for timber operations except for permitted equipment crossings as agreed upon by NMFS, CDF&G, and USFWS, and roads. - *(5)* watershed analysis and/or PWA protocol will be used to determine the priorities and road armoring standards to be used on all existing haul roads and stream crossings -road segments within Band # must be mitigated as follows: - extend Band #1 (Restricted Harvest Band) on the opposite side of the watercourse as the existing road an equivalent distance of the road prism (width, fill, etc.) - for RMZ road crossings the first 15' of road extending inland from the permanent vegetation transition zone as defined in the 97 FPRs is exempt from this mitigation - full suspension yarding only; conditions (not locations) where full suspension is not possible will be identified in the HCP. For these conditions, yarding will be conducted in a manner that avoids ground disturbance that may deliver sediment to a watercourse to the maximum extent practicable. Where ground disturbance occurs PL will treat (e.g., through seeding, mulching, etc.) all sites with exposed mineral soil that can reasonably be expected to deliver sediment to a watercourse (e.g. gullies, ruts). - trees damaged in the cable yarding corridors must be retained in place - retain ALL portions of down wood (i.e. LWD/LOD) except as defined as slash in the Z=Berg-Nejedly Forest Practice Act Article 2, 4525.7 *no forest chemical use (herbicides, pesticides, fertilizers)	Bank Stability, LWD protection and recruitment, temperature, sediment filtration, microclimate, soil compaction

	2) Selective Entry Band 10-100' -	- PalCo later seral prescription - single tree selection - minimum 276 sq ft pre harvest conifer basal area, per acre of RMZ, each side - minimum 240 sq. Ft post harvest conifer basal area, per acre of RMZ, each side (measured over 0-100' width of RMZ) - no more than 40% of the conifer basal area may be harvested in a single entry - tree sizes and quantity distribution retained as per HCP Appendix 14 (Aug 25 >97) [if replacement size classes must be used to obtain the stated size distributions, the replacement size class must come form the next higher class] - basal area measurements will be made for conformance no less than every 200' lineal segment of RMZ as per the CFPR=s 916.4(b)(2) - maximum 1 entry per 20 years - No sanitation salvage or exemption (including emergency exemptions) harvest (as defined in >97 CFPR=s) except for emergencies as per agreement with NMFS, FWS, and CDF&G in accordance with the approved HCP - EEZ for timber operations except for permitted equipment crossings as agreed upon by NMFS, CDF&G, and USFWS, and roads. -watershed analysis and/or PWA protocol will be used to determine the priorities and road armoring standards to be used on all roads inside Band #2 (limited entry band) Surface area covered in roads will be included in all calculations of basal area. - full suspension yarding only; conditions (not locations) where full suspension is not possible will be identified in the HCP. For these conditions, yarding will be conducted in a manner that avoids ground disturbance that may deliver sediment to a watercourse to the maximum extent practicable. Where ground disturbance occurs PL will treat (e.g., through seeding, mulching, etc.) all sites with exposed mineral soil that can reasonably be expected to deliver sediment to a watercourse (e.g. gullies, ruts). * Trees damaged in the cable yarding corridors must be retained in place. retain ALL portions of down wood (i.e. LWD/LOD) except as defined as slash in the Z=Berg-Nejedly Forest Practice Act Article 2, 4525.7 * trees felled during current harvesting and approved THP roads construction are not considered down wood for purposes of retention. * felled hazard trees are considered down wood and are to be retained in the general vicinity * trees that fall naturally onto a roads, landings, harvest units are considered down wood and are to be retained in the general vicinity * no forest chemical use (herbicides, pesticides, fertilizers)	Bank Stability, LWD protection and recruitment, temperature, sediment filtration, microclimate, soil compaction

CLASS III * measured slope distance	Slope <30%	- Equipment Limitation Zone (ELZ) extending 25' from the stream edge, or to the drainage divide, or ridgeline of the Class III stream whichever is less - No fire ignited in zone - Stabilize skid trails as per the >97 FPR=s as per an approved THP in accordance with the Class I and II standard - ground based equipment in the ELZ is acceptable if less resource damage will occur by operating in the ELZ, as per an approved THP - where the above measure applies, all tractor road watercourse crossings must be flagged on the ground prior to preharvest inspection and shown on the THP map in order to be adequately evaluated for the potential to generate sediment - no removal of down wood in the channel - no removal of any portion of down wood within ELZ except for emergencies as per agreement with NMFS, FWS, and CDF&G in accordance with the approved HCP * trees felled during current harvesting and approved THP roads construction are not considered down wood for purposes of retention. * felled hazard trees are considered down wood and are to be retained in the general vicinity * trees that fall naturally onto a roads, landings, harvest units are considered down wood and are to be retained in the general vicinity	Sediment Metering, LWD delivery to Class I and I=s
	Slope 30%-50%	- ELZ extending 50' from the stream edge, or to the drainage divide, or ridgeline of the Class III stream whichever is less - No fire ignited in zone - Stabilize skid trails as per the >97 FPR=s as per an approved THP in accordance with the Class I and II standard - ground based equipment in the ELZ is acceptable if less resource damage will occur by operating in the ELZ, as per an approved THP - where the above measure applies, all tractor road watercourse crossings must be flagged on the ground prior to preharvest inspection and shown on the THP map in order to be adequately evaluated for the potential to generate sediment - no removal of down wood in the channel - no removal of any portion of down wood within ELZ except for emergencies as per agreement with NMFS, FWS and CDF&G in accordance with the approved HCP * trees felled during current harvesting and approved THP roads construction are not considered down wood for purposes of retention. * felled hazard trees are considered down wood and are to be retained in the general vicinity * trees that fall naturally onto a roads, landings, harvest units are considered down wood and are to be retained in the general vicinity	

	Slope >50%	- EEZ (Equipment Exclusion Zone) extending 100' from the stream edge, or to the drainage divide, or ridgeline of the Class III stream whichever is less - no fire ignited in EEZ. - ground based equipment in the EEZ is acceptable if less resource damage will occur by operating in the EEZ, as per an approved THP - where the above measure applies, all tractor road watercourse crossings must be flagged on the ground prior to preharvest inspection and shown on the THP map in order to be adequately evaluated for the potential to generate sediment - no removal of down wood in the channel - no removal of any portion of down wood within EEZ except for emergencies as per agreement with NMFS, FWS and CDF&G in accordance with the approved HCP * trees felled during current harvesting and approved THP roads construction are not considered down wood for purposes of retention. * felled hazard trees are considered down wood and are to be retained in the general vicinity * trees that fall naturally onto a roads, landings, harvest units are considered down wood and are to be retained in the general vicinity	
<u>ROAD NETWORK</u>	Assessment of existing road network and sediment sources	<u>After issuance of the ITP</u>: - Complete watershed analysis and road inventory according to PWA protocols on a planning watershed basis within prioritized hydrologic units and schedule listed below: <u>Decade #1</u>: Elk River, Freshwater Creek, Lawrence Creek, Yager Creek (including Lower, N.F., Middle, S.F.) <u>Decade #2</u>: Van Duzen, Middle Eel <u>Decade #3</u>: Larabee / Sequoia, Mattole, Salmon, Bear. - For THPs outside of priority areas, sediment source assessments must be complete on a planning watershed scale.	
	Restoration of sediment delivery sites for non-THP related roads	<u>Prior to issuance of the ITP:</u> - Based on PWA analysis, complete recommended road storm proofing on high and medium risk sites, on at least 50 miles per year. <u>After issuance of the ITP:</u> - Based on watershed analysis, complete recommended work on high and medium risk sites, on a planning watershed basis, within the prioritized hydrologic units and schedule listed above. Variations from this schedule will be conducted only upon approval of the agencies	Sediment Control

Storm-proofing or upgrading THP related roads	Prior to issuance of the ITP: - All THP related roads and landings shall comply with specifications described in Handbook for Forest and Ranch Roads (Weaver 1994) After issuance of the ITP: All THP related roads and landings shall comply with specifications described in Handbook for Forest and Ranch Roads (Weaver 1994) until which time a completed watershed analysis results in the identification and completed work on high and medium risk sites, on a planning watershed basis or the watershed analysis indicates that sediment is not a problem.	

	Maintenance and Use of existing roads	- Other than at watercourse crossings or crossing approaches, permanent roads utilized in riparian management zones shall be treated by rocking, chip sealing or paving to help prevent loss of road surface material. - Roads which utilize an inside ditch shall have ditch relief culverts spaced no greater than the specifications listed in Handbook for Forest and Ranch Road (Weaver 1994). <u>Roads where storm proofing has been completed:</u> - road use for log hauling will cease when it results in a visible increase in the suspended sediment levels of water that drains from the road surface, or within inboard road ditches, directly into Class I, Class II or Class III streams. -<u>Roads where storm proofing is not yet complete</u>: Road uses shall cease after precipitation is sufficient to generate overland flow off the road or capable of leaving the road if entrapped Roads use for hauling shall not resume until 48 hours without any precipitation or until the road surface is dry[2]	
	Monitoring Road Network	- All PL roads and their associated drainage facilities and landings except for roads, facilities and landings abandoned under the FPRs, will be inspected at least once annually. The annual inspections will include: 1) examination of the road prism, cut slopes, and fill slopes for signs of erosion, slippage, or impending mass failure and surface erosion; 2) all culverts for signs of blockage or perching, 3) all erosion control measures to ensure proper condition and/or operation, and 4) all inboard ditches to ensure sufficient water transport capacity. Road inspections will be conducted early enough to allow all necessary road repairs to be conducted before the next winter rainy period. During the winter-spring rainy period, PL staff using company roads will note all observed occurrences of road slippage, erosion or impending mass failure, blocked culverts, and failures of erosion control measures. All observed occurrences will be immediately reported to PL's road manager for corrective work. - Routine corrective work on inside ditches, culvert capacity and outflow, cross drains and water bars, and non-routine work such as rocking road surfaces, replacing culverts, and stabilizing fill slopes should be completed before the next winter rainy period. Work needs identified during the wet season will be conducted as soon as weather permits after the site is identified.	

2 A wet road is that which the road moisture is higher than found during normal watering (dust abatement) treatments.

HILLSLOPE MANAGE-MENT	Mass Wasting Extreme, Very High and High Landslide Hazard Zones (including Inner Gorges)	Apply process described in Pre-Permit Application Agreement in Principle [Paragraph 1B(iv)] Refer to text appended to this table. - the area of 50, 271 acres of Ano data@ must be accounted for in a hazard rating prior to the final approval of the HCP - For areas inside the 170', or 100' RMZ that also fall in the extreme, very high or high landslide hazard zones, the Hillslope Management-Mass Wasting process applies. - a minimum silvicultural prescription for these areas is that described for each specific Band #1,2 or 3, respectively.	
	Surface Erosion	- treat all sites of exposed mineral soils, caused by forestry activities, within RMZ=s, EEZ=s, and ELZ=s that are equal to or greater than 100 sq ft. - treat all sites less than 100 sq ft of exposed mineral soils in RMZ=s, EEZ=s, and ELZ=s that are on hillslopes greater than 30% if the site can deliver fine sediment to the watercourse. - treatments can include revegetation or other erosion control measures including but not limited to seeding and mulching - watercourse crossings in RMZ=s, EEZ=s and ELZ=s shall be treated to prevent sediment delivery. Watershed analysis and/or PWA protocol will be used to determine the priorities and road armoring standards to be used on all such crossings. - cable corridors (cable roads) that divert or carry water away from natural drainage patterns or to channelize run-off that reaches watercourses shall have waterbreaks installed at intervals as per skid trail prescriptions by Weaver et al. (1994)	
BURNING		- no mitigation will be required for damage caused by the actual fire, unless PalCo or its agents have been issued a citation or violation for the fire by CDF - mitigation may be required if PalCo or its agents are found to be out of compliance with their burning permit - mitigation may be required for fire management, including suppression and rehabilitation efforts if PalCo or its agents are found in violation of their burn permit (citation or violation) by CDF - BMP=s need to be developed for managing prescribed burns (including brush piling, fire breaks, ignition techniques, prescriptions for environmental conditions permitting ignition, etc.),.	Sediment Control and slope stability
MONITOR-ING & RESEARCH		Agency team in cooperation with PalCo will be developing a monitoring strategy.	
ADAPTIVE MANAGE-MENT WITH TRIGGERS		Implement watershed analysis as per Feb 3, 1998 framework.	

	Construction of new roads	New roads and landings shall comply, at a minimum, with specifications described in Handbook for Forest and Ranch Roads (Weaver 1994) including but not limited to the following: - Roads shall be constructed as single-lane that allow for the safe passage and transportation of equipment with periodic turnouts (road width generally 12 to 14 feet) except as approved by NMFS, FWS, and CDF&G. - Roads shall be constructed primarily on slopes under 50%. - Roads shall be located outside riparian management zones, except for RMZ crossings, which shall be minimized - Roads shall be constructed by outsloping, or maintained with rolling dips (or ditched roads maintained by well-spaced ditch relief system) - Avoid construction of roads in high risk situations (e.g., inner gorge, road alignments crossing unstable terrain, alignments crossing slopes greater than 50 percent, or degraded watersheds[2]) unless potential roads and specifications are evaluated by a Certified Engineering Geologist (CEG) and submitted to the agencies with the THP for review in advance of THP pre-harvest inspection. - When culverts are proposed for Class I fish bearing or restorable watercourses, the RPF shall be required to demonstrate that the CMP will conform to best management practices related to culvert installation including but not limited to: 1. Culverts will be sized to provide 100 year peak flow passage using any of the methods approved by the Forest Practices Rules. - 2. the company shall contact NMFS, USFWS, and CDF&G to discuss the installation prior to submission of THP if it wishes to install the culvert using methods that are not consistent with NMFS' culvert guidelines (currently under development). In such cases, if the notified agencies have concerns regarding such culvert installation, they shall communicate such concerns to the RPF and CDF. . - No road or landing construction or reconstruction during the winter period or any other time of the year during any of the following conditions: a. During periods of measurable rainfall b. Following any rainfall of one-quarter inch or greater, there shall be a minimum of 48 hours of no measurable rainfall prior to resumption of work activities. - Landowner and his designated representatives, shall be responsible for all road construction and maintenance.

1 Watershed condition should be evaluated according to the categories listed in Technical Rule Addendum #2.

MASS WASTING AVOIDANCE STRATEGY FOR THE INTERIM PERIOD
(March 1998 through 3 years post ITP issuance or until watershed analysis is complete)

1. Interim prescriptions

   a. The "high" mass wasting potential areas will be treated the same as the "very high" ranked areas. Thus:

      i. In areas where the potential for mass wasting is rated as "extreme", in addition to inner gorges[3], headwall swales[4], and unstable areas[5], no harvesting and no new roads will be allowed without a geologist's report recommending alternative prescriptions that are approved by CDF. The alternative prescriptions will not increase the risk of hillslope failure in the area, as determined by the professional registered PalCo geologist. The geologist's written report must accompany the THP when submitted for review.

      ii. In areas where the potential for mass wasting is rated as "very high" or "high," no new roads and no operation of heavy equipment off of existing roads will be allowed without a geologist's report recommending alternative prescriptions that are approved by CDF The alternative prescriptions will not increase the risk of hillslope failure in the area, as determined by the professional registered PalCo geologist. The geologist's written report must accompany the THP when submitted for review.

2. Consultation

   a. The NMFS, CDFG, and EPA or Regional Water Quality Board, and shall be notified of all THPs that may be submitted on areas of extreme, very high and high mass wasting potential in addition to inner gorges, headwall swales, and unstable areas. If the PalCo geologist determines that management beyond the default prescriptions will not increase the risk of hillslope failure in the area for the ranking of an area, a written report must be prepared discussing the determination. If the company plans to go forward with prescriptions that exceed the defaults, the

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[3] Inner gorge as used here is defined as that area of the watercourse bank situated immediately adjacent to the watercourse channel, having a sideslope of 65% or greater, and extending from the edge of the channel upslope until the slope becomes less than 65% or for a distance of 400 ft. (slope distance) whichever is less.

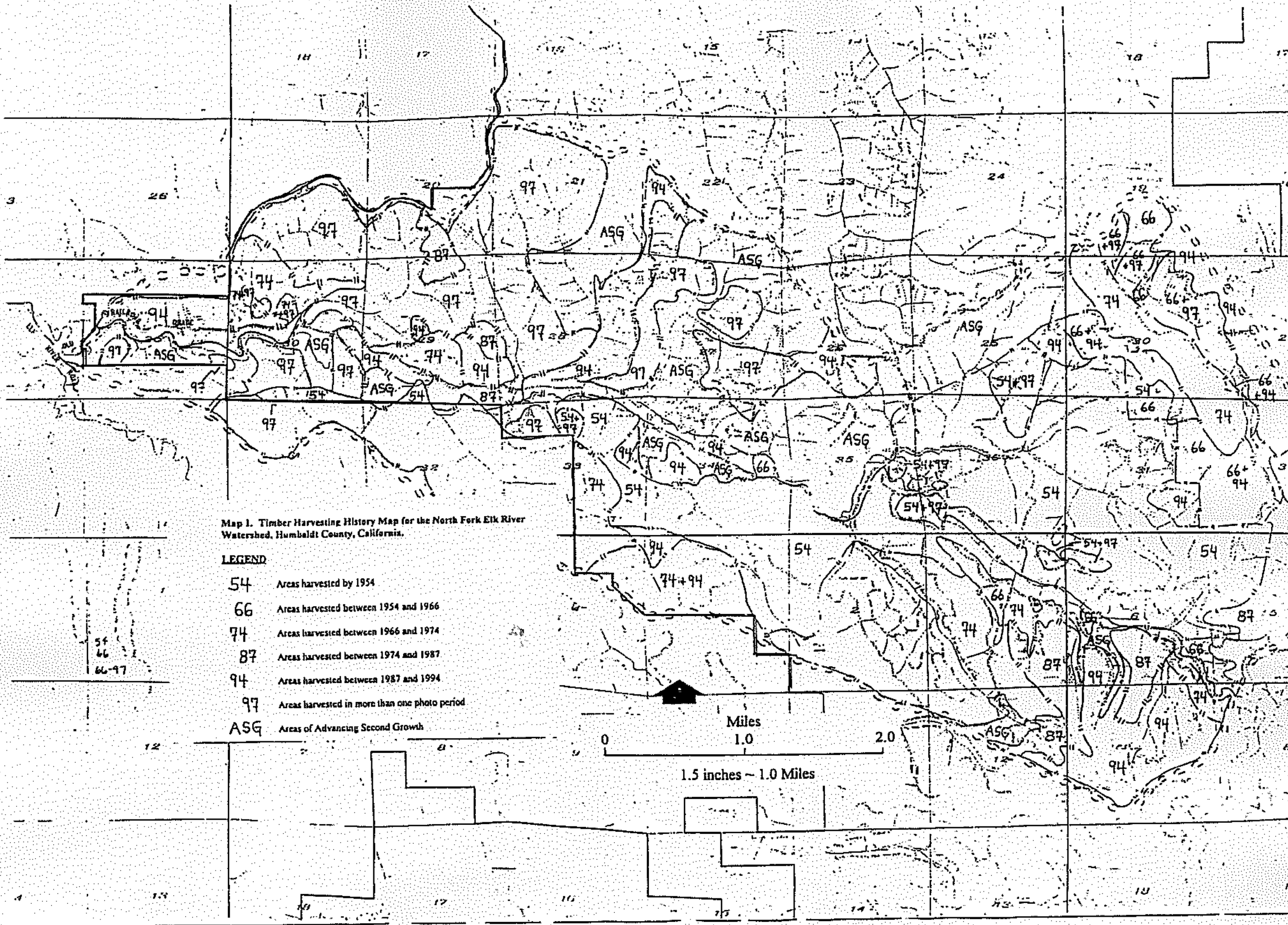
[4] Headwall swale is defined here as a concave depression, with convergent slopes > 65%that is connected to a watercourse via a continuous linear depression (a linear depression interrupted by a landslide deposit is considered continuous for this definition).

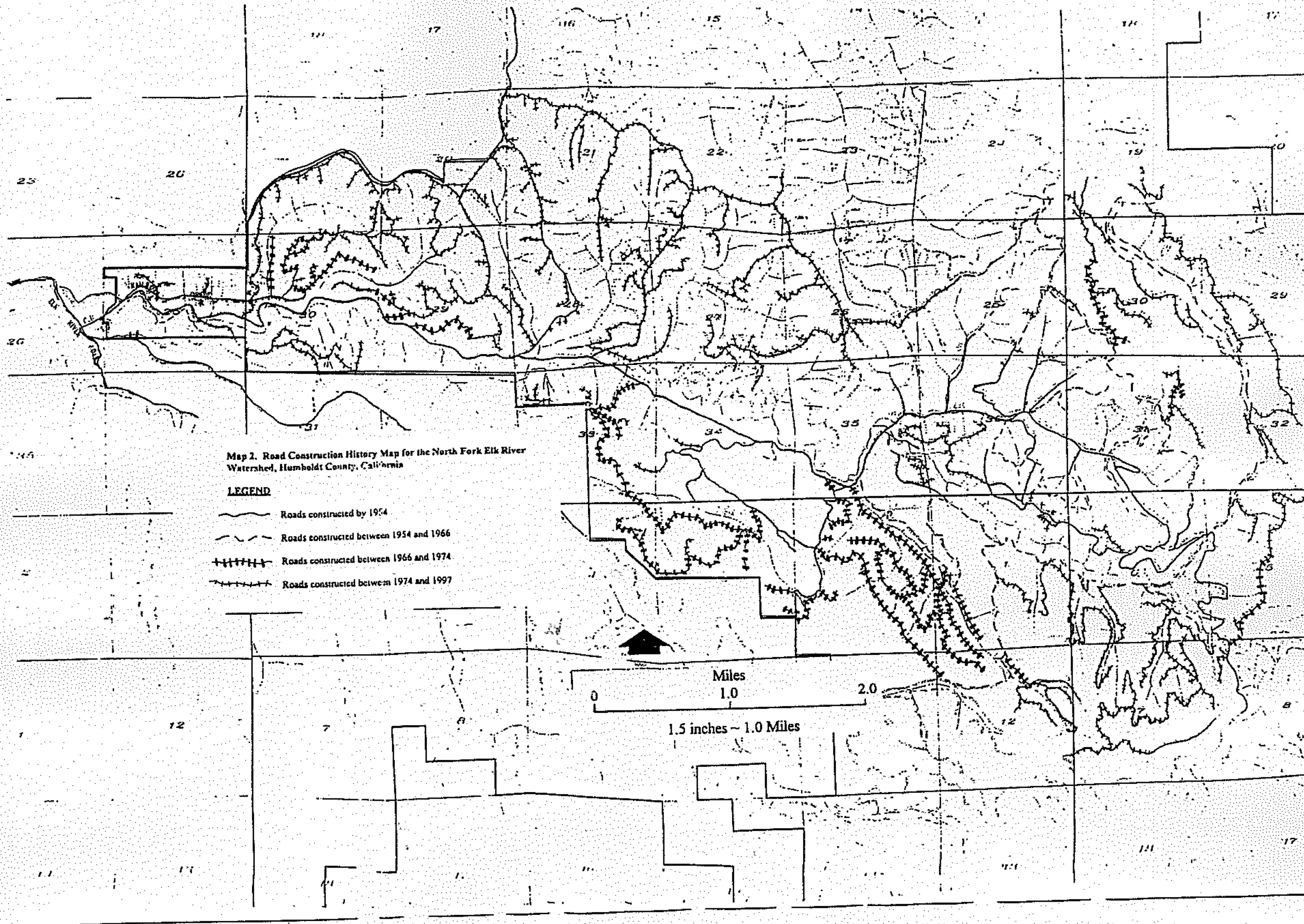
[5] Unstable areas are characterized by slide areas or by some or all of the following: hummocky topography consisting of rolling bumpy ground, frequent benches, and depressions; short, irregular surface drainages begin and end on the slope; tension cracks and head wall scarps; slopes are irregular and may be slightly concave in upper half and convex in lower half from previous slope failure; evidence of impaired ground water movement resulting in local zones of saturation within the soil mass which is indicated at the surface by sag ponds with standing water, springs, or patches of wet ground. Some or all of the following may be present: hydrophytic vegetation prevalent; leaning, jackstrawed or split trees are common; pistol butted trees with excessive sweep may occur in areas of hummocky topography (leaning and pistol butted trees should be used as indicators of unstable areas only in the presence of other indicators).

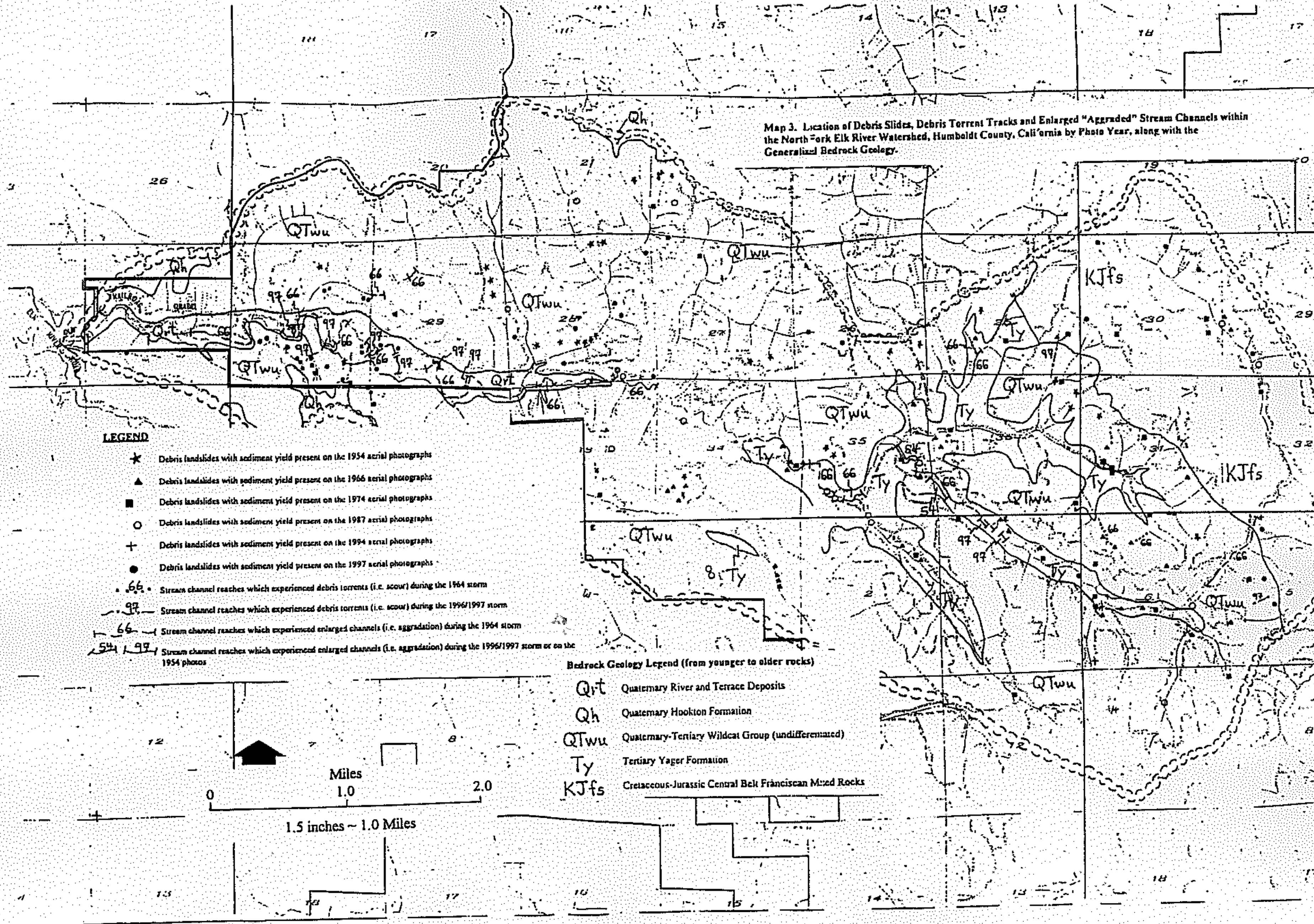
company shall consult with NMFS, EPA or Regional Water Quality Board, and CDF&G prior to THP submission. The consultation shall include copies of the proposed THP, including the THP number, a map of the area proposed for harvest, silviculture prescription, and a copy of the geologist's report. PalCo shall seek approval, acceptance, or notice of Ano response@ from the agencies. If the notified agencies have concerns regarding the harvest proposal, they shall communicate such concerns to the RPF and CDF within 30 days of receipt of materials from PL or until the close of the public comment period, whichever is longer. Results of the consultation must accompany the THP when submitted for review.

3. Scope

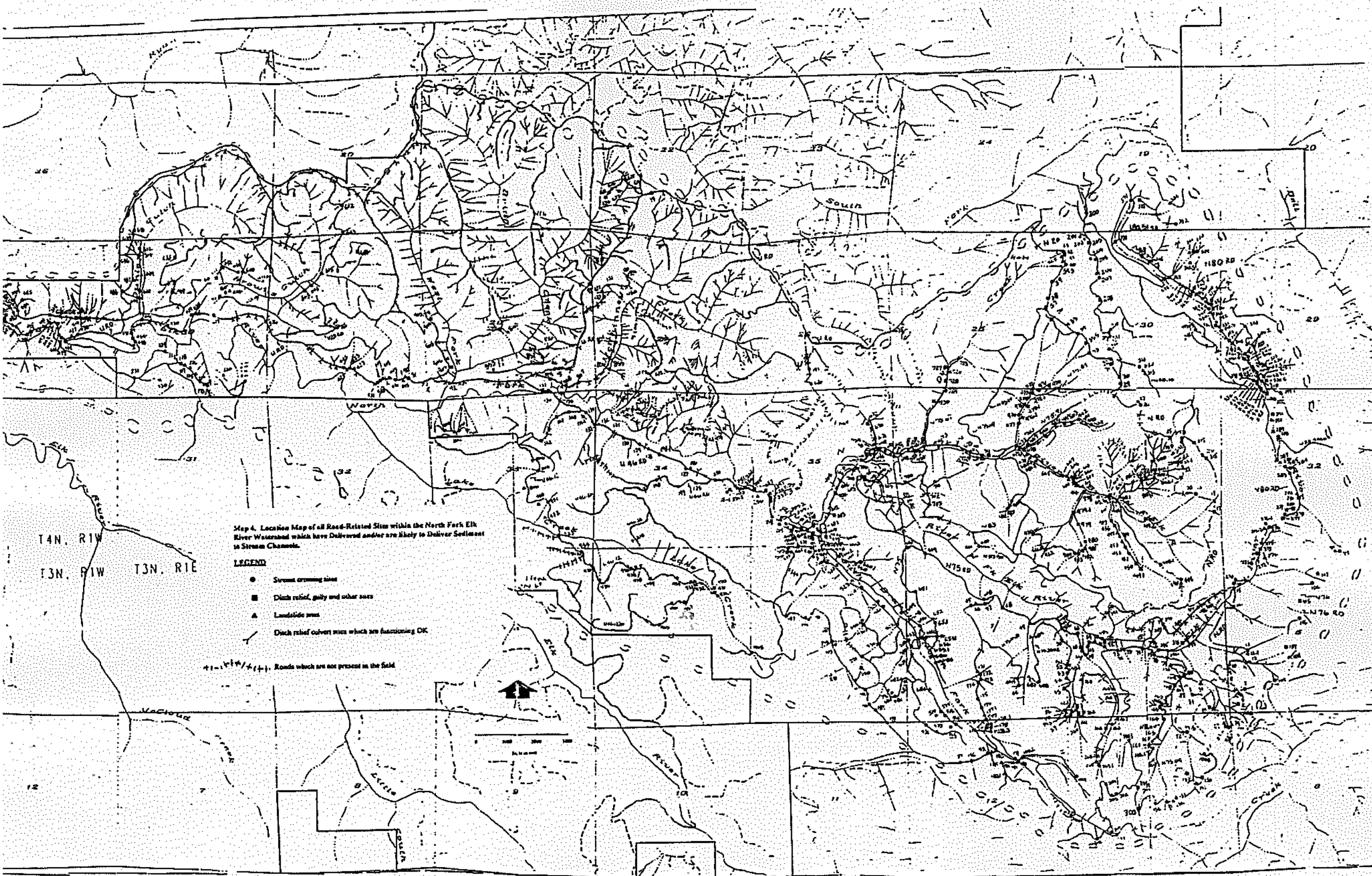
a. These provisions shall replace all measures proposed in the 7 January 1998 Interagency Strategy that deal with mitigation of mass wasting risks for the "interim" period of March 1998 through 3 years after issuance of the ITP.


Map 1. Timber Harvesting History Map for the North Fork Elk River Watershed, Humboldt County, California.
LEGEND
54 Areas harvested by 1954
66 Areas harvested between 1954 and 1966
74 Areas harvested between 1966 and 1974
87 Areas harvested between 1974 and 1987
94 Areas harvested between 1987 and 1994
97 Areas harvested in more than one photo period
ASG Areas of Advancing Second Growth
Miles
0
1.0
2.0
1.5 inches ~ 1.0 Miles

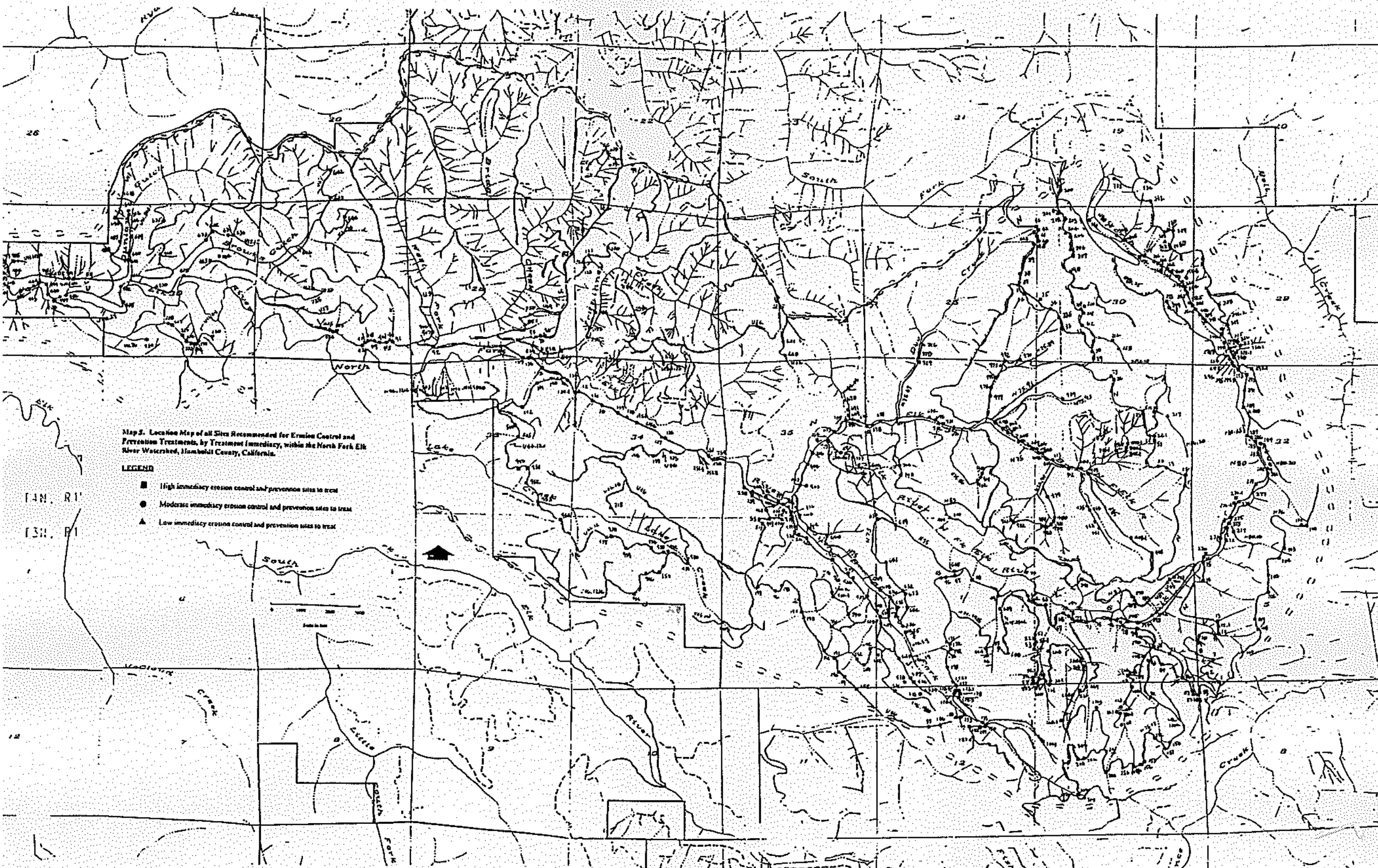

Map 2. Road Construction History Map for the North Fork Elk River Watershed, Humboldt County, California
LEGEND
Roads constructed by 1954
Roads constructed between 1954 and 1966
Roads constructed between 1966 and 1974
Roads constructed between 1974 and 1997
Miles
0
1.0
2.0
1.5 inches ~ 1.0 Miles



Map 3. Location of Debris Slides, Debris Torrent Tracks and Enlarged "Aggraded" Stream Channels within the North Fork Elk River Watershed, Humboldt County, California by Photo Year, along with the Generalized Bedrock Geology.



Map 4. Location Map of all Road-Related Sites within the North Fork Elk River Watershed which have Delivered and/or are likely to Deliver Sediment to Stream Channels.



Map 5. Location Map of all Sites Recommended for Erosion Control and Prevention Treatments, by Treatment Immediacy, within the North Fork Elk River Watershed, Humboldt County, California.